WATER POWER

A technical journal devoted to the study of all aspects of Hydro-electric developments

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Editor: H. STOREY, M.C., B.Sc., M.I.M.E.

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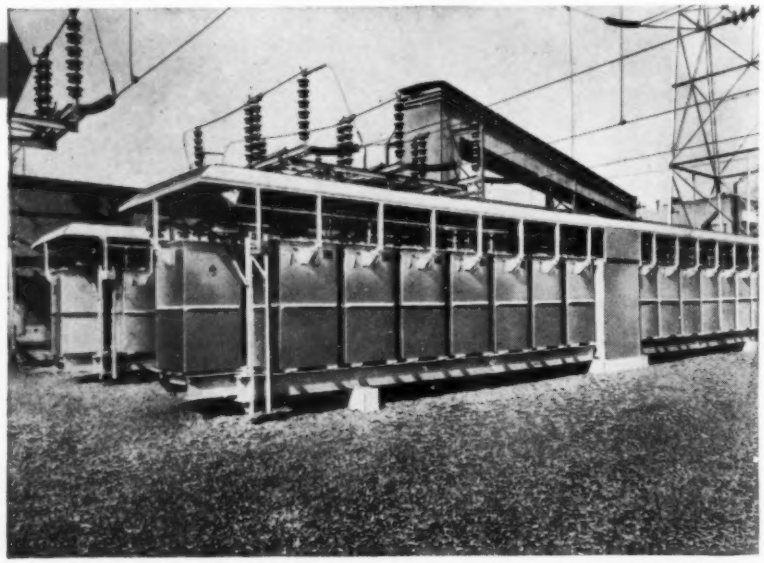

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Hydro-Electric Progress in Scotland

DURING 1953 the North of Scotland Hydro-Electric Board* connected over 20,000 new consumers to their mains, and after meeting all operating costs, and interest and sinking fund chargeable against revenue, finished with a net profit of £14,532. Capital expenditure during the year amounted to £15,878,000, the total capital expenditure to the end of 1953 being £98,622,000 of which £63,266,000 is accountable to hydro-electric schemes.

At present, hydro-electric plant already in operation (including the prewar Grampian scheme) has an overall capacity of 398,665 kW and an annual production of 950 million kWh. Plants under construction have a designed capacity of 420,800 kW and are estimated to have an annual production of 1,263 million kWh. Finally, those in course of promotion and survey have an estimated capacity of 307,500 kW and an annual output of 1,094 million kWh. That is, the schemes in being and in projection have a total capacity of 1,126,965 kW and an annual output of 3,307 million kWh.

Ten years ago it was estimated that the total potential water-power resources of the Highlands—not all of them economic—were equivalent to 6,000 million kWh per annum, but further investigation has suggested that a more accurate figure would be nearer 10,000 million kWh per annum. In the first ten years of the Board's existence, it can be said that about one-third of the potential water-power resources coming under their jurisdiction is either in process of survey, construction or operation, and this represents a notable achievement.

Curiously enough although the demand for electricity increased by 109 million kWh or 12½ per cent. over the 1952 figure in the year, the maximum peak demand of the consumers in the Board's area at 284,000 kW was only 9,000 kW or 3 per cent. more than the figure for 1952. This low peak, however, was rather fortuitous as it was largely due to the mild December of 1953.

Under their contract with the British Electricity Authority, the Board supplied 304 million kWh in 1953 to Central Scotland or about the same as in 1952. The maximum peak load supplied was 193,000 kW which exceeded by 8,000 kW the amount which the Board have contracted to deliver.

Contracts were placed and work is either begun or about to begin on the Breadalbane scheme, which will consist of two sections—the Killin and St. Fillans—having a combined capacity of 85,500 kW; the Shin (40,000 kW); Lower Moriston (32,000 kW); Allt-na-Lairige (6,000 kW); and Kilmelfort (2,000 kW).

Outstanding progress has been made in rock tunnelling, some 95,000 ft. having been driven during the year. This is equivalent to 1½ miles per month and represents a considerable improvement on the previous years, the best of which, in 1952, did not quite reach a mile per month. The Ceannacroc tunnel is 14,000 ft. long and 12 ft. in diameter, and it was driven by the Mitchell Construction Company in 57 weeks at an average rate of 1,000 ft. per month. The tunnel was driven from several working faces, on one of which an average rate of 600 ft. per month was achieved for five months. The previous best rate of driving was 540 ft. per month in a 10 ft. tunnel in 1952 and even this was nearly double the average rates of driving that size of tunnel achieved in the period 1946 to 1949. The total length of tunnel driven in the eight years since the Board began tunnelling operations is now 72 miles while contracts for a further 25 miles are outstanding. The firm of A.M. Carmichael Limited, Edinburgh, who have been tunnelling for the Board at Errochty, Glascarnoch and Shira have driven 21 miles in all and have 10½ miles of tunnel in hand. These satisfactory results have been largely due to improvements in mechanical equipment employed, to better organisation and to greater skill and experience on the part of the tunnelling crews. Also more and more use is being made of pneumatic concrete placers for placing the lining.

At the beginning of the year twelve dams were in course of construction and before the year ended work was begun on five more, and contracts let for a further five. The Gaur dam, part of the Tummel

* See "North of Scotland Hydro-Electric Board Report and Accounts, 1st January 1953 to 31st December 1953." H.M. Stationery Office, Edinburgh. Price 2s. 6d. net.

scheme, was completed during the year.

As already mentioned in WATER POWER* the decision to use concrete made from blast-furnace slag by the Trief process in the Cluanie and Loyne dams in Upper Glen Moriston was carried a stage further by the completion and formal start-up of the plant in October. A large number of precast facing blocks have been produced and will be used as shuttering for containing the bulk concrete. In addition to this development the possibility of using fly ash from power stations fired by pulverised coal is being investigated with a view to economising in the amount of cement needed in concrete dams and a trial of this method will shortly be made at the Lawers dam. A further innovation as a means of saving cement and reducing costs, was the decision to build the Allt-na-Lairige dam of prestressed concrete. It is the first time that this principle has been applied to dams in Britain although it has been used fairly extensively abroad. The dam will have a maximum height of 73 ft. and a length of 1,375 ft. and the prestressing is provided by groups of steel rods or cables anchored in the cut-off wall.

In view of the heavy transport cost on cement the Board is exerting considerable pressure to have more produced locally. In an average year the Board uses about 70,000 tons and as the transport from southern sources amounts to about £1 per ton the total additional cost is very onerous. The total cost of the cement is also increased by the fact that it is supplied in paper bags which can only be used once and add a further cost of 14s. 6d. per ton. To reduce this cost the Board have completed arrangements for cement supplies for the Lairige scheme in Upper Glen Fyne to be delivered to the site in bulk containers as is widely done on similar schemes on the Continent.

Road building represents a substantial item in the Board's programme and some 91 miles of public road and 160 miles of access or private roads to dams, aqueducts, and other sections of their schemes, have either been built, reconstructed, or are in course of construction. Many of these roads will be of considerable advantage to the public and will be of great value in promoting the general economy of the Highlands.

In all, fourteen power stations are at present under construction, ten on the surface and four either wholly or partly underground. In some of the earlier stations more than one generating set was often necessary to safeguard against breakdown, but as the stations multiply and interconnection is more complete, this need has diminished and it is now possible to design stations with a maximum of simplicity and economy. The new Gaur station represents a case in point and six other stations now under construction will have only one generating set—Shira, Lawers, Invergarry, Quoich, St. Fillans and Comrie.

A final point of interest lies in the arrangements which the board have in hand for the reading of consumers' meters. In a widespread and sparsely populated area in which the Board operates, meter reading is necessarily an expensive matter and efforts have been made for some time to interest consumers in making their own readings and returning the results on prepaid postcards. To this end cyclometer-dial type meters are being installed and they give rise to less possibility of error than the rather complicated arrangement of clock dials.

* December 1953 issue, page 446

World Power Conference Arrangements

THE period to be occupied by the Brazilian Sectional Meeting of the World Power Conference and by the associated tour has been extended by two days. The period now is July 25 to August 10, 1954. The technical sessions will be held from July 25 to 31 at the Hotel Quitandinha, Petropolis, which is about one hour's drive from Rio de Janeiro. The tour will take place from August 1 to 10.

The Fifth World Power Conference will take place at Vienna during the summer of 1956. This will be the first Plenary World Power Conference to be held since the Fourth World Power Conference at London in 1950. Invitations for 1956 had also been issued by the German Federal Republic and Yugoslavia, but these invitations were withdrawn in order to make possible the unopposed acceptance of the invitation from the Austrian National Committee.

Future Sectional Meetings are likely to take place in Canada in 1958 and in Switzerland in 1960. A preliminary invitation has recently been received from the Australian National Committee, and it is possible that a Sectional Meeting may be held in Australia in 1961.

Owen Falls Progress

THE Sixth Annual Report of the Uganda Electricity Board for the year ended December 31, 1953, contains interesting details of progress on the Owen Falls development. In spite of considerable technical difficulties, not the least of which was the closing of the last temporary opening in the dam, satisfactory progress was made with the civil engineering. The last cofferdam for the main dam was dewatered on June 22, and by the end of the year all cofferdams had been removed except that enclosing the site of sets 4 to 10. By the end of the year the main dam west of the headrace and the intake and headrace dams had all been substantially completed, and the office building was nearing completion. The concrete floors of sets 1 and 2 had been completed, the superstructure steelwork had been erected as far as set 4, cladding completed up to set 2, and foundation work was in various stages of progress on sets 3 to 10.

The tailrace of the first three sets was flooded on November 13, and on December 23 the headwater rose to first-stage operating level of 3,697 ft., permitting the testing of the first 15 MW set. This set is now in running order and it is hoped to have the second set in commission by April 29, when the Queen is due to open the station. The spiral casing of the third turbine had been completed and tested by the end of the year and main components on site, and the spiral casing of the fourth and the draught tubes of the fifth and sixth sets were under construction. Three turbine intake gates had been erected and tested, and the 30 ton travelling crane for operating trash racks and bulkhead gates is in service.

Four generator transformers, two station auxiliary transformers and two 33/66 kV feeder transformers had been erected by the end of the year, and the first stage of the 33 kV switching station almost completed. The transmission line from Jinja to Kampala was changed over from 33 kV to its designed voltage of 66 kV on October 11, and erection of the double-circuit 132 kV steel tower lines from Owen Falls to

Tororo, and Owen Falls to Kampala was commenced. Due to a revision of the development plans on the part of Kilembe Mines Limited the proposal to erect a transmission line from Jinja to western Uganda had to be abandoned, but negotiations were in progress to supply electricity to Nairobi and other towns in Kenya.

The total direct cost of the Owen Falls scheme, including provision for the civil-engineering works required to accommodate ten 15 MW generating sets and the actual installation of the six of these sets now on order is estimated at nearly £11 million, to which over £2 million must be added for capitalised interest and head office management charges.

Trade Delegation to Burma

ACCORDING to a Board of Trade announcement, a British delegation is now visiting Burma to consider how British industry can assist in the Burmese Government's plans for developing the resources of the country. The delegation consists of Lord Burghley (leader), chairman of A.C. Cossor, Birmid Industries and other companies; Mr. H. Nimmo, chairman, Southern Electricity Board; Brig. M. Pearce, overseas manager, George Wimpey & Co. Ltd.; Mr. W. H. Sharp, joint managing director, Thomas Smith & Sons (Rodley); Mr. K. H. Tuson, partner, Mackness and Shipley; Mr. G. P. Brownie, Federation of British Industries, adviser to the delegation; and Miss M. M. Mocatta, Board of Trade (secretary).

This news gives some topical interest to Mr. Logan's article, published on page 142 of this issue, describing a survey he conducted for the Burmese Government for a hydro-electric scheme for the Bawgata Valley—a scheme that unfortunately had to be put into cold storage owing to civil disorder. It is to be hoped that in the changed circumstances this scheme may be revived.

Power in Christchurch, New Zealand

A REPORT by the Municipal Electricity Department, Christchurch, New Zealand, refers to the necessity for new power stations to avoid irksome restrictions caused by drought in the hill country. It is noted with pleasure that progress with the extensions to Waitaki station is ahead of schedule, and that dates for completion of various sections of the Roxburgh station were introduced into the contract. Both stations are now urgently needed to satisfy the ever-growing demand for electricity. Restrictions last winter were unavoidable owing to the drought conditions, and resulted in a heavy loss to the department. The loss reacted on funds available for capital works and necessitated the early raising of a £90,000 loan.

Seyhan Project, Turkey

FURTHER to the note we published on this project in our October issue of last year we are now able to give further information. It appears that the International Engineering Corporation made preliminary studies and prepared the initial engineering report but that the firm Knappen-Tippetts-Abbett-McCarthy are the consultants engaged by the Government of Turkey for the preparation of the final plans and specifications, together with the supervision of the constructional work involved. The contract for the work has, we understand, been awarded jointly to the Morrison-Knudsen International Co., Inc., and Garanti Insaat, Ltd., of Istanbul.

Messrs. Knappen-Tippetts-Abbett-McCarthy have been interested in Turkish hydro-electric developments since 1949 and in addition to the final designs for the Seyhan project have also been responsible for the investigations and reports on the Gediz and Menderes valley schemes. Bidding plans and specifications for the Demirkopru dam and power plant on the Gediz River are now being prepared, and it is anticipated that a start on the construction work will be made in the final quarter of the present year.

U.S. Power Increases

AMONG new U.S.A. generating units and recent increases to existing plants are a 40 MW unit at Northern States Power Company's Granite Falls station, increasing the plant size to 60 MW; and a 106 MW unit at Consumer Power Company's Justin R. Whiting plant, which raises the capacity of that station to 276 MW. Recently the first 106 MW unit went on the line at Ohio, Edison Company's new plant.

In Indiana, Richmond is planning to spend $5,750,000 for a new generating station; and the second section of a 230 kV transmission line that connects the new Wabash power station to Columbus power station is expected to be completed shortly. At the new station on the Wabash river two 100 MW units are expected to be in commission shortly.

Clearwater No. 2 power plant on N. Umfaqua River, Oregon Ridgeland plant, has added a new 150 MW unit; St. Clair plant, Detroit, started a 150 MW turbo generator, and the Giant Oak Creek power plant has been increased to the extent of 120 MW.

Electrical Progress in Victoria

THE Thirty-Fourth Annual Report of the State Electricity Commission of Victoria, Australia, reveals that the financial results for the year ended June 30, 1953, were the most successful of any year to date, following the lifting of restrictions on the use of electricity that had become necessary during the post-war years. The year's surplus was £343,151 after providing full interest and depreciation, strengthening reserves to the extent of £514,644 and meeting £1,050,000 on account of interest.

During the financial year 45 MW of new plant had been installed, and a further 110 MW was due to be in commission by the end of 1953.

On the hydro-electric side work was proceeding on Kiewa No. 4 Development. Excavation for the underground power house was almost complete, the steel lining was being placed in the pressure tunnel, and the headrace and tailrace tunnels were being concrete lined where required. The manufacture and delivery of the four 15·4 MW units were in progress. No. 3 development was receiving supplementary water from Bongong Creek, and No. 1 development was proceeding at a reduced tempo, but work on other parts of the scheme was in abeyance.

For the Eildon project two 60 MW sets were on order and were due for completion in 1956.

On the Kiewa-Melbourne 220 kV transmission line 58 per cent. of the towers had been completed and stringing of cables begun.

Fig. 16. View of Kemano Valley, showing main Kemano Camp No. 5, aerial tramway, camps on the 1,600 and 2,600 ft. levels, and Horetzky Creek Valley

Kitimat

This project has the distinction of being the largest hydro-power development as yet built by private enterprise and it also comprises the largest underground power house, the largest pressure conduits, the most powerful impulse turbines, and the greatest firm output of any single hydro station in the world.

PART TWO

THE two inclined sections were driven from the bottom upwards. A pilot rise, 6 ft. wide by 10 ft. high, was first excavated across which a wooden partition was constructed, the under compartment forming a muckway and the upper a manway and service road. A track was provided for a car which was hauled and lowered by a hoist at the bottom, the return sheave being kept as close to the heading as possible. The last few feet of the heading were approached by walkway steps. Both the muck chutes were equipped with pneumatically operated discharge gates at the bottom.

It was originally planned that the drilling and the erection of the wooden partition should be carried on simultaneously, but this method was found to be impracticable as the necessary supplies were delayed for both operations. Some hazard was also introduced by having one crew working below the other, and it was consequently decided that the same crews should do both jobs, first blasting out a few drilling rounds and then dropping back to advance the timber work. Average progress was 8·8 ft. per day per heading, about the same amount of time being taken for ad-

Fig. 17. Kemano/West-Tahtsa drilling crew in position on their jumbo, showing the positioning of the 21 Atlas-Copco rock drills

vancing the timber as for drilling and blasting.

On completion of the pilot rises the timber was removed and the excavation enlarged to 15 ft. in the round, working from the top downwards, the inset in Fig. 14 showing the method adopted. The rate of progress averages about 50 ft. per heading per day. The rock is loaded into trucks at the bottom through the control gates to which reference has already been made. As the work proceeds tracks are laid for installing the steel penstock liner sections, Fig. 14 showing the method of lowering them into position.

The eight branches from the penstock are 9 ft. in diameter and the corresponding tailrace branches are 16 ft. wide and 21 ft. high. These relatively small-section tunnels were drilled from portable platforms, the muck being removed by slusher scrapers for the penstock branches and by overhead tractor loaders in the tailrace tunnels. The scrapers were used to drag the rock into the power house where ample height was available for it to be handled into trucks by overhead tractor loaders.

The Power House

In excavating the power house and valve chamber recourse was made to long-hole diamond drilling in order to obtain trim excavation lines and to avoid the serious timing problems involved in the conventional drilling-blasting-mucking cycle in an excavation 80 ft. wide and rising to a height of 120 ft. to the top of the parabolic arch. The upper two-thirds of the tailrace tunnel was driven into the power house as

Fig. 18. Aerial view of the Kenney dam

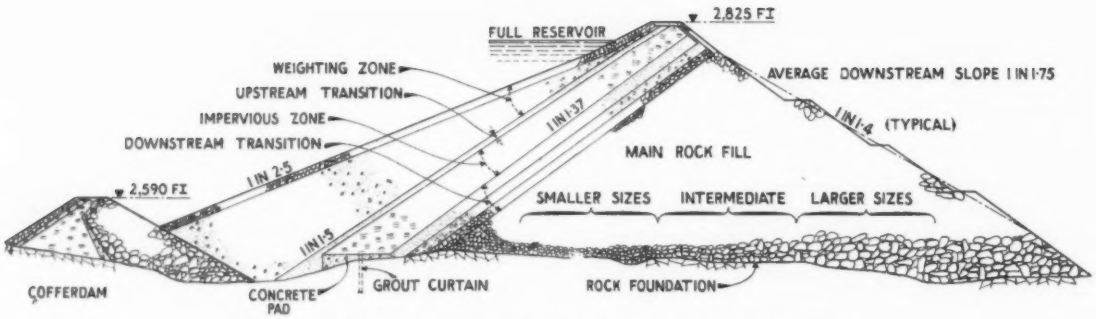


Fig. 19. Maximum cross section of Kenney dam, height 325 ft.

far as the centre line of the turbine units and from it a 27 ft. by 27 ft. drift was extended along the entire length. A small 8 ft. by 8 ft. ventilating tunnel was driven into the power house at springline level for permanent ventilating purposes. Above the 27 ft. by 27 ft. drift a further drift, 10 ft. by 12 ft., was carried not only along the entire length of the present power house (712 ft.) but also extended to a total distance of 1,142 ft., i.e. the ultimate length of the power house when equipped with the full quota of 16 turbines. Seven vertical slots were raised to connect the two longitudinal drifts and thence carried up through the roof of the upper drift to points lying 2 ft. beyond the trim line of the arch. These upper slots were 10 ft. wide and spaced at 120 ft. centres, and from them diamond drill blast holes were bored for a distance of 55 ft. in either direction. As soon as the first three slots were drilled, successive rings of holes were blasted, thus extending the drift in an upward direction. The muck was pushed into the lower series of vertical slots by power shovels and received by trucks in the lower drift. The final ring of shots constituted the trim holes and broke the rock off to the arch line with a minimum of shock to the remaining roof rock. In one section there was a patch of weak blocky rock and here a 20 ft. section was carried up to the arch line which was then heavily roof bolted before any blasting was done at the sides. These were progressively opened with lightly charged shots and the roof bolting extended along the roof sides to make the whole perfectly safe until the concrete arch could be inserted. After the whole length of roof had been excavated and secured by a concrete arch, the main body of the rock was blasted out by vertical holes bored by a diamond drill. The area over the lower longitudinal drift was first removed and the sides then extended until the wall limits were reached. A few preliminary shots quickly opened up enough space to enable the muck to be loaded out by a standard 1½ cu. yard shovel fitted with an electric drive. This muck was hauled out by diesel trucks and used to fill in an area along the Kemano River for flood protection. Although diamond drilling costs more per foot than drilling with percussive machines, it has the merit of permitting uninterrupted drilling in one area while blasting and mucking out is proceeding in other areas. In consequence it results in a more economical use of manpower and equipment than the

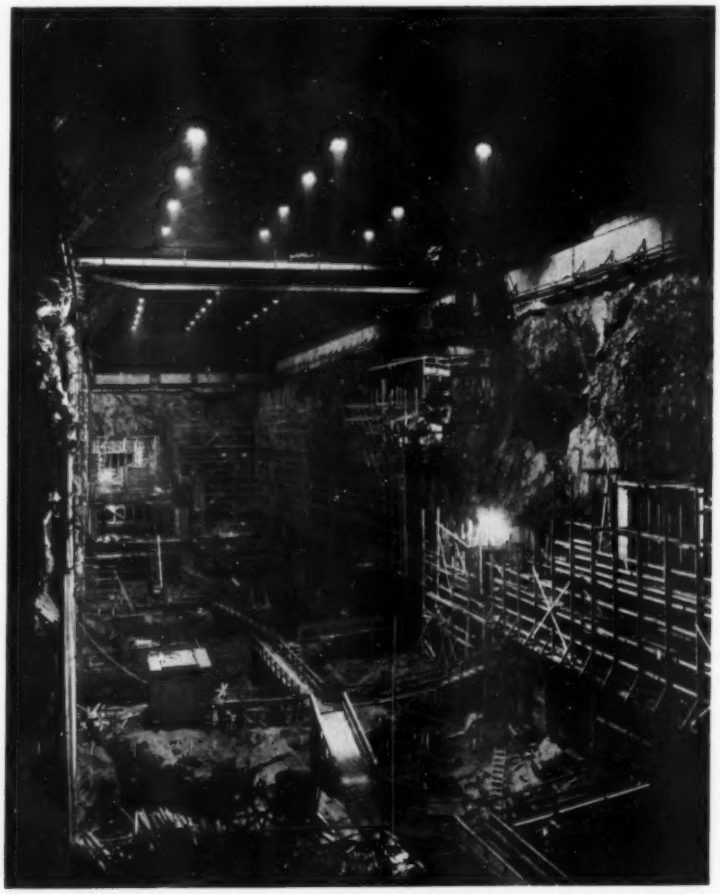


Fig. 20. General view of power house looking north-east from inner end of access tunnel

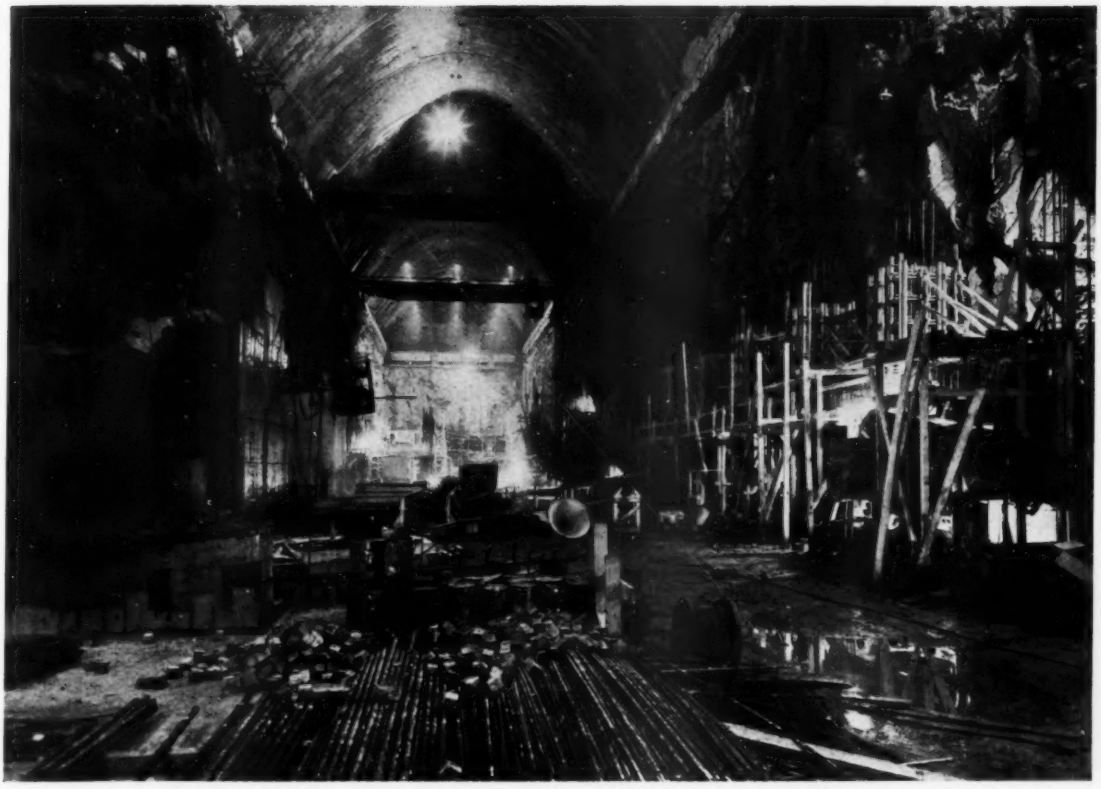


Fig. 21. View of the power house from the service and control-bay area

conventional drilling, mucking, and cleaning-up cycle. About 0·43 lb. of 60 per cent. Giant gelignite was used per cu. yard of rock excavated. The success with which the long-hole drilling technique was attended in the power house led to the adoption of this method in the smaller valve chamber, also with excellent results.

The portal for the access tunnel to the power house is situated at some height above the natural level of the ground, making it somewhat awkward as a route for the excavated material but of corresponding convenience for moving and installing the heavy equipment, as it enters the power house at generator floor level. The tunnel for the tailrace was excavated in two sections, the upper two-thirds only being first taken out in order to provide a better access route and to avoid possible trouble with water, as the invert is well below ground level. The lower bench will not be taken out until the power units are ready to be placed in position. Both tunnels were drilled from truck-mounted jumbos and excavated by ¾ cu. yard crawler shovels loading the muck into road trucks. The access tunnel is 27 ft. wide and 31 ft. high while the tailrace tunnel is at present 27 ft. square, but when the invert is blasted out to a further depth of 13 ft. the total height will be 40 ft. The cable tunnel for the oil-immersed 230 kV power cables is 18 ft. wide, 13 ft. 6 in. high and 1,437 ft. long.

In commenting on the methods employed in these underground excavations, F. T. Matthias and C. W. Abrahamson* pointed out that nothing completely new was introduced and the interest lies in the extraordinary variety of the work, the large quantity of material used, and in the supply problems presented by the widespread nature of the operations and the difficult terrain. The quick mobilisation of the constructional equipment and staff to sustain simultaneously four main tunnel headings, four penstock headings and various points of attack in the power house made exacting demands on the contractors. Some 950 miners had to be recruited and as few of them were experienced their training into competent crews was a major task in itself. This task was complicated by a high turnover rate as rather special temperamental qualifications are required for men to settle down in remote regions, especially when alternative work is fairly easily obtained in more urbanised areas. The general contractors for all this underground work are the Morrison-Knudsen Company of Canada Limited.

A number of considerations governed the decision to place the power house underground. The pressure head is very high and exposed steel penstocks for a power production of the magnitude developed at Kitimat would have involved a costly expenditure for steel. With the pressure conduits situated well underground, the pressure surges arising from sudden load rejection can be met by the enclosing rock and a corresponding reduction made in the amount of steel used. External penstocks would have had to be of considerable length and would have required expensive maintenance, but by placing the station underground very much shorter conduits could be used and

* See reference in March issue, page 99.

Fig. 22. General view of Kemano power house looking south. The lower scaffolding in the upstream wall has been removed to facilitate work on the turbines

the discharge from the water wheels carried in a freely flowing tailrace tunnel. Other disadvantages of surface pipelines in the Kitimat area were vulnerability to enemy attack, risk of forest fires, snow or rock slides on the steep mountain slopes and the uncertainty of finding secure rock anchorage foundations for the supports. Against these, of course, must be offset the cost of the tailrace tunnels, the access tunnels and the extra length of cables required between the generators and transformer bank or switchyard. The cost of excavating an underground chamber as compared with erecting one at the surface leaves nothing much

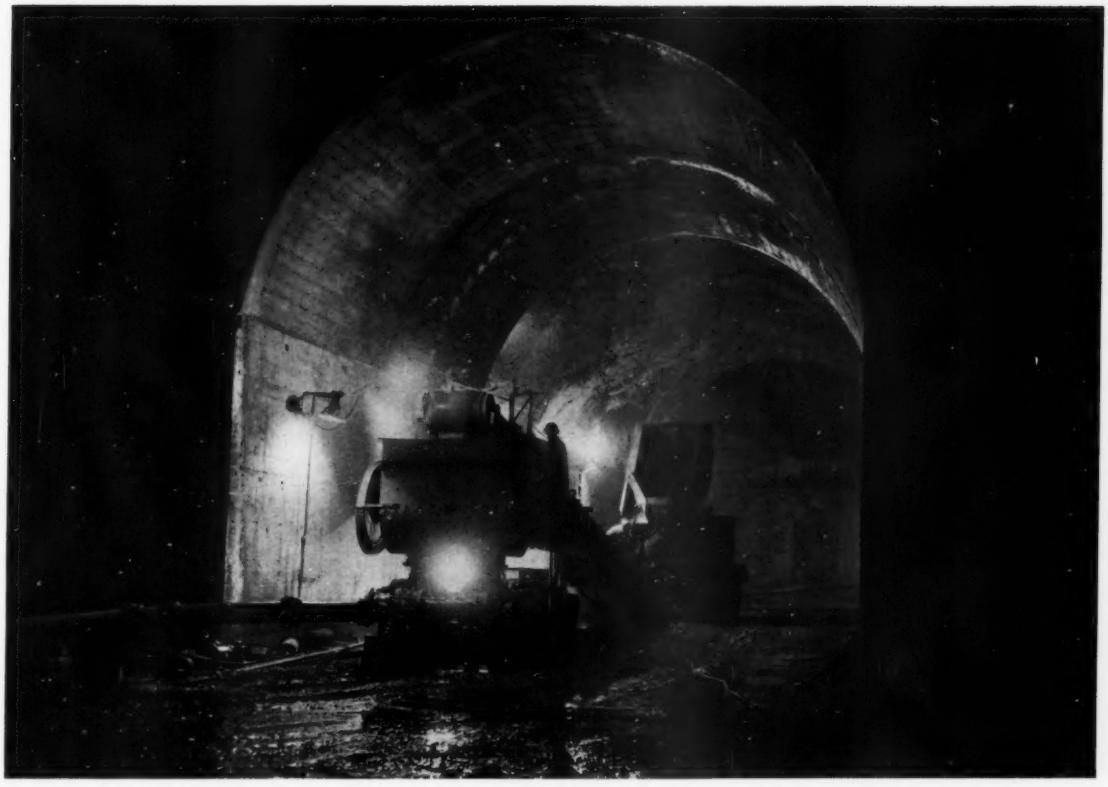


Fig. 23. View taken from within the power-house cavern looking upstream through the penstock access tunnel, showing Pumpcrete equipment

Typical Equipment and Performance Data

Rock Drills: Six Ingersoll Rand, D.A. 35's.

"Jumbo": 16′ 0″, One Deck on 36″ Gauge, 60″ Rail.

Mucking Equipment: One No. 75 Conway Loader.

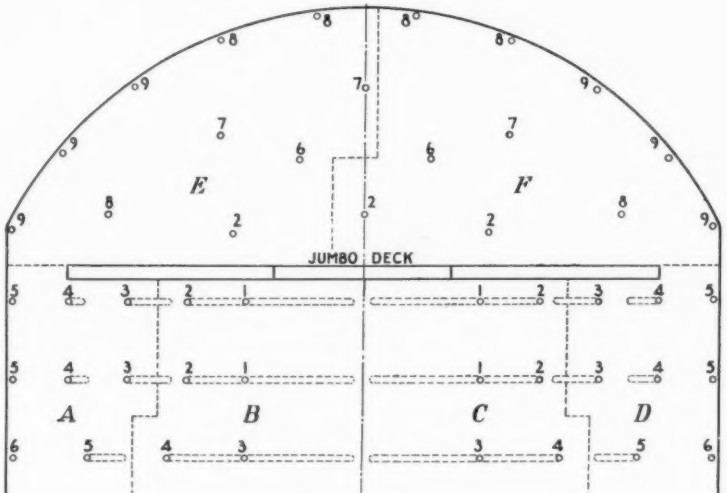


Fig. 24. Drilling and blasting pattern of 18 ft. × 13 ft. 6 in. cable tunnel

Locomotives: Two 8 Ton Battery, one spare Battery.

Cars: Four 5 yard, side dump, Granby Type.

Drill Steel: 1¼″ Round Atlas; Lengths, 5′ 8″—9′ 8″ and 11′ 8″. 11″ 0′ Cut holes, all others 9′ 0″.

Bits: Detachable 2″ "Carset," Tungsten Carbide.

Bit Size in Inches

2″ to 1 15/16″ Starter, new to
1 15/16″ to 1 7/8″ First gauge change after grinding
1 7/8″ to 1 13/16″ Second gauge change after grinding

Gauge change 2″ to minus 1 15/16″ after 30 to 60 feet of drilling

Average total life (footage) per bit .. 600 ft.

Cycle:

Time in Hours and Minutes		*Typical Shift Heading Crew*	
Drilling	1-35	Shifters & Walkers	2
Load & Blast	0-50	Miners & Helpers	14
Ventilation	0-30	M.M. Operator	1
Mucking	3-35	Motormen	2
Misc.	1-55	Electricians & mechanics	2
Total Cycle	8-25	Typical Shift Crew	21

No. of holes drilled per round: 58 holes.

Total feet drilled per round: 600 feet.

Time period per foot of heading advance: 52 minutes.

Cubic yards per foot of advance: 8·9 c.y.

Cubic yards per 9′ round: 80·2 c.y.

Cubic yards per man shift: 3·87×2·2 short tons = 8·5 tons.

Powder consumption per cubic yard, 1½″×8″, 40% Giant Gel.: 5·41 pounds.

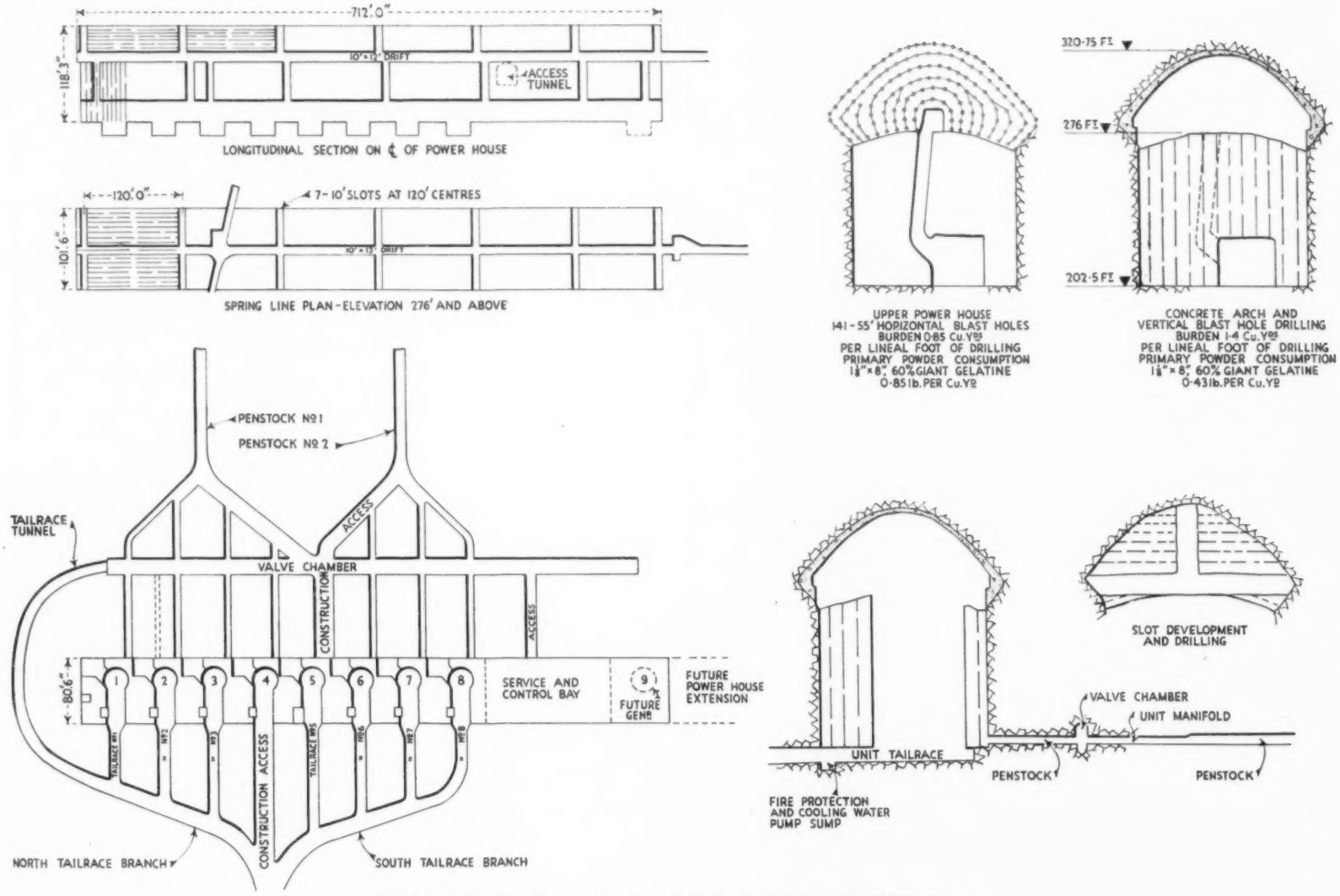


Fig. 25. Diagrams illustrating procedure in excavating power-house area

Fig. 26. Cable tunnel showing wall pours for lining sections, looking downstream

to be considered since the advent of the tungsten carbide bit has so greatly reduced the major cost of excavation work; and a further point in favour of an underground station was that it would enable the work to be carried on during the winter season.

The pressure-conduit system branching off from the 25 ft. diameter tunnel to supply the first eight of the 16 impulse-wheel generating units consists of a surge shaft constructed in the rock; a steel breeches piece bifurcating into two 11 ft. diameter pressure conduits and each controlled by an oil-pressure-actuated butterfly valve; and an air-relief valve to admit air into the conduit whenever it is drained for inspection. Each 11 ft. diameter pressure conduit is 4,000 ft. long and the butterfly valve is situated about 300 ft. below the wye piece. At the downstream end each of the 11 ft. conduits branches out into four 5 ft. diameter pipes, each of which serves one of the 140,000 h.p. turbines. About half-way between the centre line of the generating units and the major wye in the manifold a spherical valve is fitted; the valve is located in the valve chamber and drains into the tailrace.

In this way each of the 11 ft. diameter pressure conduits serves four units and is controlled by a butterfly valve and by a connection to the surge chamber, which serves to limit the pressure rise on load rejection and to provide increased flow to meet additional load.

Under operating conditions the hydrostatic pressure in the conduit will be borne partly by the steel and partly by the enclosing rock which is necessarily stressed to an amount commensurate with the superincumbent weight. To ascertain the properties of this rock a 10 ft. diameter test sphere was encased in concrete in a chamber excavated out of the rock and subjected to a pressure of 3,600 lb. per sq. in.—about three times the pressure to which the conduit will be subjected. Analysis of the figures obtained showed that a modulus of 1,500,000 lb. per sq. in. could be relied upon. At the valve chamber openings and in the power house, however, the steel is required to carry the whole of the pressure stress and has been considerably thickened at these points. Including $\frac{1}{16}$ in. allowance for corrosion, the steel liner in the conduit ranges from a thickness of $\frac{9}{16}$ in. at the upper end to $1\frac{15}{16}$ in. at a point 150 ft. upstream from the first wye in the manifold. Below here the plate thickness is $2\frac{1}{2}$ in. and the 5 ft. diameter branches connecting with the tubine flanges are constructed in $2\frac{3}{4}$ in. plate. All plate of 1 in. thickness or under is of A.S.T.M. Specification No. A285, Grade B, while the thicker plate was manufactured to Specification No. A201 and is of Grade A firebox quality. The spherical valves controlling the flow to individual turbines are double seated and have cast-steel bodies. The body seat rings are movable and their operating controls are so arranged that the upstream seals are normally disengaged. They are 51 in. in diameter and have been designed to pass a maximum flow of 555 cusecs under normal operating conditions. The maximum water velocity through the valves will be 39·2 ft. per sec. and that in the 5 ft. diameter branch pipes will be 23·6 ft. per sec.

Access to the power house is gained by a tunnel 1,400 ft. in length, 27 ft. wide and 31 ft. high, which also serves as a ventilating duct for the incoming air. Outgoing air passes through a small tunnel at the power house spring line. Emergency travelling ways are afforded by the cable tunnels and the outgoing air duct. When completed the power house will accommodate 16 vertical, single-runner, four-nozzle

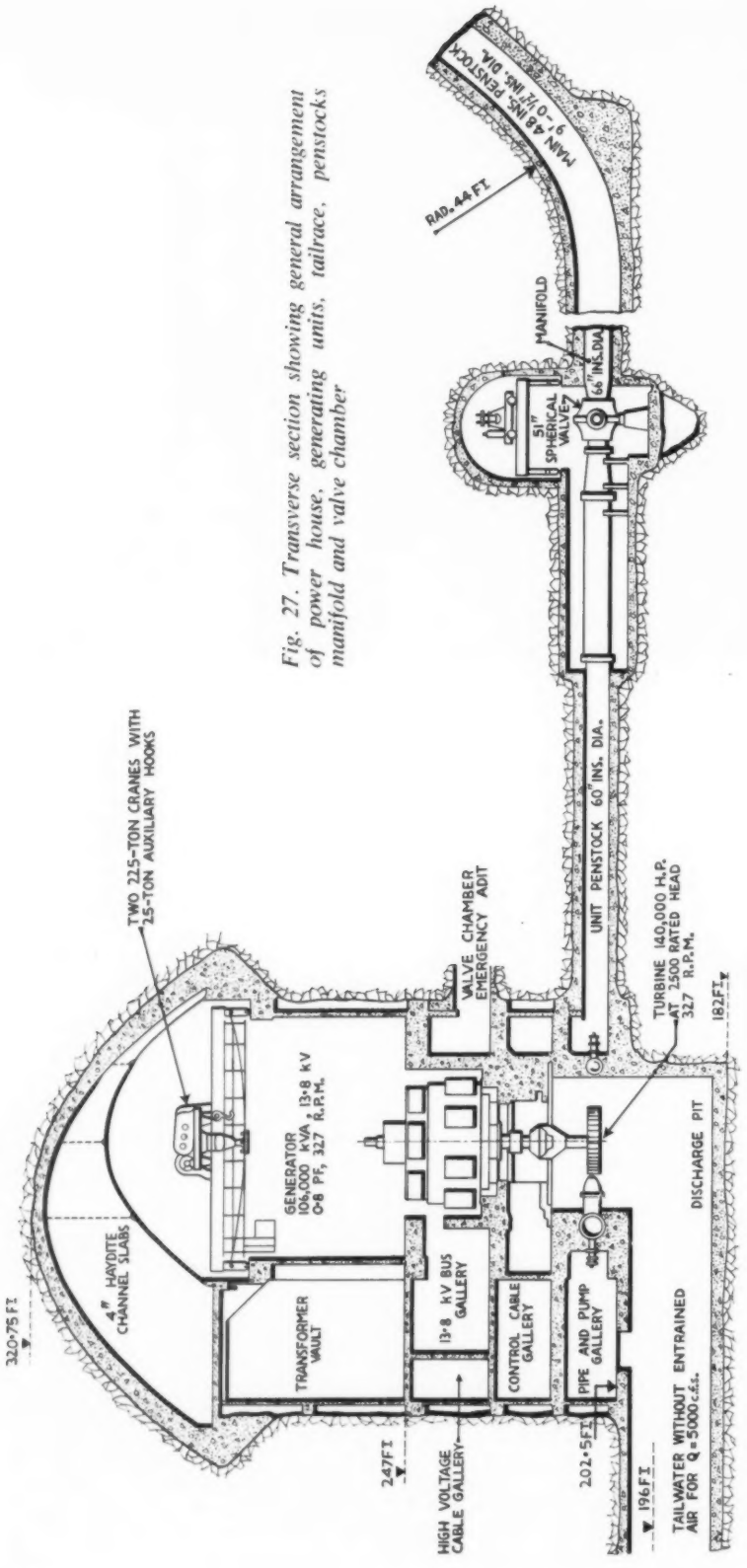


Fig. 27. Transverse section showing general arrangement of power house, generating units, tailrace, penstocks manifold and valve chamber

Pelton turbines, each rated at 140,000 h.p. at 327 r.p.m. It is 1,000 ft. long, 80 ft. wide and 135 ft. high. Each turbine is directly connected to a vertical, three-phase, 60 cycle, 13,800 V, 0·8 power factor generator rated at 106,000 kVA at 60°C. rise and 122,000 kVA at 80°C. rise. These generators will be able to carry 115 per cent. of the 60°C. rating continuously. Each pair of generators will feed into a double primary bank of three single-phase 71,000—89,000 kVA transformers, stepping up to 300 kV, and situated in the power house on the downstream side of the generators, full provision being made for fire protection and for draining the oil into the tailrace in the event of a transformer tank rupturing. Also the ventilation has been so devised that there is no risk of any combustion products contaminating the atmosphere of the power house or approach roads.

The 300 kV supply from the transformers is delivered to a switchyard at the surface through oil-filled cables. These cables, eight in number, are over 2,000 ft. long and carry a single copper conductor, paper insulated, and are charged with oil at a pressure of 60 lb. per sq. in. Generator relay protection consists of generator differential, split-phase differential using primary current transformers, and back-up relays comprising phase overcurrent and neutral. The transformer banks are protected by ground differential and transformer differential relays embracing the outdoor high-tension circuit breakers. Service current for the station is provided at 600 V by a 2,500 kVA transformer tapped from the generator leads (13·8 kV). All the controls and relays are housed underground, the 300 kV cables being carried by open racks in two cable tunnels.

The centre line of the nozzles is fixed at an elevation of 210 ft., the wheel pits for each group of eight turbines connecting with a separate tailrace. These tailraces comprise tunnel sections, one 1,050 ft. long and the other 1,100 ft., and open cut sections which discharge

Fig. 28. Excavation of tailrace tunnel, Kemano power station

into the Kemano River, at an elevation of 174 ft.

Transmission

Each of the eight oil-filled 300 kV cable circuits serves two generator units and feeds the switching station through an air-blast breaker having a rupturing capacity of 6 million kVA symmetrical, and thence to either of the two busses through motor-operated selector disconnect switches.

There are four outgoing circuits, the first nine miles of the transmission system comprising two double-circuit tower lines which climb gradually to an elevation of about 1,000 ft. At this point they feed into a switching station provided with the motor-operated selector disconnect switches. The outgoing lines from here consist of two single-circuit transmission lines which pass over an elevation of 5,300 ft., traversing a distance of 10·6 miles. Here there is a further switching station from which two double-circuit tower lines traverse the remaining distance to the terminal station at the aluminium-reduction plant at Kitimat.

The design of this transmission system is based on 1,250,000 kW firm delivery at Kitimat, and consideration had to be given to the harsh conditions existing in narrow snow-raked valleys that are subject, in places, to snow and rock slides. Snow may be 20 ft. deep or more during the winter and the icing may give rise to searching problems. Aluminium production is necessarily a continuous process and any interruption of the power services for more than a few hours entails a costly loss, and it was for this reason that a particularly rugged construction was adopted for the transmission lines. To gain at least partial information on the conditions likely to be encountered a test span was erected between two 26 ft. high aluminium towers on the summit of the Kildala Pass at an elevation of 5,300 ft. In the short period available the maximum ice loading observed amounted to 2·4 lb. per lineal foot of conductor, this being very much lower than was expected and incomparably lower than the loading encountered on the Puy de Dome in south-central France where there is an experimental station at an altitude of 4,806 ft. Here ice loadings of 27 lb. per ft. have been registered and the design of the Kemano-Kitimat line has taken this figure into consideration.

For the following technical particulars of the actual transmission line between Kemano switching station and the aluminium works at Kitimat we are indebted to a paper* presented to The Engineering Institute of Canada by F. L. Lawton, M.E.I.C., Chief Engineer, Power Department, Aluminium Laboratories Limited, and J. S. Kendrick, M.E.I.C., Assistant Manager, Project British Columbia, Aluminum Company of Canada Limited.

For the double-circuit tower lines, standard ACSR 54/19 (Falcon) 1,590,000 CM cross-section conductors are being used, with an outside diameter of 1·545 in. and weighing 2·032 lb. per ft., the ultimate tensile strength being 55,400 lb. The double ground wire at the terminals is $\frac{3}{8}$ in. diameter HS steel cable, with an ultimate strength of 50,000 lb. Insulation comprises a minimum of 15 and a maximum of 18 units per string, 10 in. by $5\frac{3}{4}$ in., 25,000 lb. M and E standard suspension units. Single strings are used for suspension points, with double strings for long spans. At strain points triple strings are used.

The basic conditions determining loads and load combinations for design of the double-circuit towers are as follows:—

(a) Ice load at 24 lb. per ft. of conductor length at 0°F., as a yield point load.

(b) 2 in. radial ice deposit on the conductor.

(c) 2 in. radial deposit of rime on the conductor combined with wind at 8 lb. per sq. ft.

(d) $\frac{3}{4}$ in. radial deposit of ice combined with wind at 11 lb. per sq. ft. and broken conductor action.

The (a) loading is used for determination of the yield point stresses, whereas the others are used for computation of stresses under normal working loads.

The specific gravity of ice was taken at 0·90 and of rime at 0·30 in the specified cases. The wind pressure on flat tower members, considering the members coated with 1 in. ice, was taken at 1·6 times the wind pressure on the conductor. The loads at conductor support points resulting from the above conditions, plus the dead load of the conductor and the hardware, together with the extreme limits of tower application as to line angle, span and slope, were used as the basis for tower design.

To account for the effect of being buried in snow (which may reach considerable depths), both as to weight and creep, all members of the tower structure below the specified height from the ground line are considered as subjected to the following loads:—

1. Towers located at or above an elevation of 3,200 ft.:—

* "Nechako-Kemano-Kitimat Hydro-Electric Power Development and Aluminium-Reduction Plant." Presented to the 66th annual meeting of The Engineering Institute of Canada, Vancouver, B.C. May 1952.

(a) Vertical load equal to (3,000–100 *h*) lb. per ft. of horizontal projection of member length (*h*=feet above ground line);
(b) Horizontal load of 300 lb. per ft. of member length acting in any direction.

These loads were applied to all members below 19 ft. above the ground line.

2. Towers located between elevations of 1,000 and 3,200 ft.:—
   (a) Vertical load equal to (1,000–400 *h*) lb. per ft. of horizontal projection of member length (*h* is feet above ground line);
   (b) Horizontal load of 100 lb. per ft. of member length acting in any direction.

   These loads were applied to all members below 13 ft. above ground line.

The values of loads (a) and (b) were independent of member cross section and their effects were each considered separately and independently of the effects of conductor loads. The towers are being designed to accommodate leg extensions within a range of 0 ft. to plus 24 ft. in 4 ft. sections.

Depending on tower location and ground conditions, various types of footings were used as follows: (a) steel grillage on earth, gravel, broken or rotten rock; (b) rock anchor, on sound, solid rock; and (c) concrete pedestal, for special conditions.

For the single-circuit tower lines through Kildala Pass, the conductor consists of ACSR, with an outside diameter of 2·295 in., a weight of 4·77 lb. per ft., and an ultimate strength of 135,700 lb., the cross-sectional area being 3,364,000 CM. The same type of insulators as used on the double-circuit tower lines are utilised, excepting that there is a minimum of 18 and a maximum of 21 units. Quadruple strings are used for suspension, and sextuple strings for strain applications. A maximum insulator swing of 36° from the vertical is allowed.

Basic conditions determining load and load combinations for the towers have been taken as follows:—

(a) Ice load of 40 lb. per ft. of conductor length at 0°F., as a yield-point load.
(b) 2·5 in. radial ice deposit on the conductor.
(c) 2 in. radial deposit of rime on the conductor combined with wind of 8 lb. per sq. ft.
(d) ¾ in. radial deposit of ice combined with broken conductor action.

Other design considerations are the same as for the double-circuit towers, except that under some conditions a wind load at 120 m.p.h. is assumed as acting on the tower surfaces.

One of the two single-circuit transmission lines across Kildala Pass will be built with steel towers, of generally conventional design. Light angle towers weigh about 33 tons each and the heavy angle-strain type substantially heavier, depending on height. The other single-circuit transmission line across Kildala Pass consists of aluminium towers, using a design of which a prototype has been successfully built and thoroughly tested. This design is a braced H-frame-type tower with five thin-walled aluminium tubes about 38 in. in diameter and a box-girder cross arm. These towers weigh about 10 tons each. They are expected to show substantial economies in transportation, erection and maintenance.

Because the electrical loading of the transmission system represents a far heavier load than has hitherto been transmitted 50 miles over a transmission system as outlined, and because the reliability of service must be high, the whole system was set upon a network analyser, taking into account the necessary characteristics of the generating equipment, the step-up and step-down transformers, the transmission circuits and the mercury-arc power-conversion equipment at the load. This investigation revealed that the transmission of 1,235,000 kW at 92 per cent. power factor over one-half of the transmission system would require about 400,000 reactive kVA of condenser capacity, or 33,000 reactive kVA per load step-down transformer bank, as contrasted with a normal maximum requirement of about 15,000 reactive kVA per bank. Maximum voltage required at the generating station terminal will be 302 kV.

At the aluminium-reduction plant, the terminal station is somewhat similar in arrangement to that at the generating station, except that there will be ultimately 12 step-down transformer banks, normally each supplying a single pot-room with bussing facilities to permit transfer of power to other loads, a bank for miscellaneous load and a spare bank. It is visualised that there may be synchronous condensers, but most of the corrective capacity will be in the form of static capacitors on the low-tension side of the step-down banks.

Aluminium-Reduction Plant

The reduction plant, or smelter, is being built partly on the delta of the Kitimat River, and partly on allu-

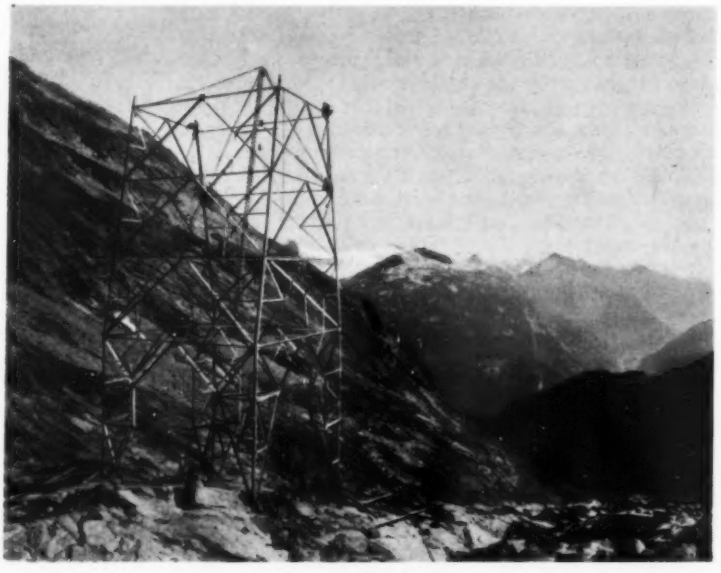


Fig. 29. Transmission towers being erected on the route from Kemano to Kitimat

Fig. 30. Stringing the overhead cables on the Kemano-Kitimat transmission line

vial fans that have been deposited on the edge of the delta by two creeks which discharge from the mountain slopes to the west.

The alluvial fans are gravel and coarse sand. Foundation conditions are fairly good, but the whole area is low, running from slightly below high tide up to 30 ft. above high tide, and the water table is high. The buildings are therefore being built on a compacted gravel fill, up to 30 ft. high at the lowest part of the site. Ample quantities of sandy gravel are available, but a haul of about two to three miles is required.

The harbour works are in the tidal region of the delta. A dredge cut is being excavated through the tidal flats, and a wharf consisting of large concrete boxes floated into place, then sunk and filled with gravel, will be built at the edge of the cut. Two rock moles have been built to contain the dredged material, in an area between the wharf and the smelter. This hydraulic fill will be used for storage space, and for some relatively light buildings; owing to its low bearing capacity no important buildings will be built on it during the early years.

Cargo-handling equipment has been developed by English suppliers to handle bulk alumina (aluminium oxide), as well as other bulk materials, and aluminium ingot. Owing to the abrasive qualities of alumina, and to the tidal range of over 20 ft., careful attention is being given to the design of bulk unloading towers.

Townsite

Not the least of the many problems is the development of a townsite intended ultimately to house 50,000 people. Planning and engineering for the townsite in such a remote area, with no initial facilities, has required the service of a number of specialists, all of whom feel that, in spite of difficulties due to climate, sloping ground, gullies and heavy timber cover, there is a unique opportunity at Kitimat to produce a community free from the inherited mistakes and congestion that cause so much expense in other places.

The townsite is across the Kitimat River and four miles up the valley from the smelter. There will be high initial costs for roads and bridges to connect the two. A railroad is also planned by the Canadian National Railways, to connect with their Prince Rupert branch at Terrace, 40 miles north of Kitimat, and a highway may be built along a parallel route.

Acknowledgments

We take great pleasure in offering our thanks to the President and Directors of the Aluminum Company of Canada Limited (ALCAN) for their kindness in allowing us to publish this article and we are indebted to many members of their technical staff for assistance in collecting the data. To Mr. F. L. Lawton, the chief engineer of the Power Department, Aluminium Laboratories Limited, we are especially indebted for the help he gave us and we should also like to extend our thanks to Mr. Duncan C. Campbell for his kind exertions in providing the photographic prints from which our illustrations are reproduced.

Ice Prevention at Hydraulic Structures

By P. J. BIER, Head of the Penstock and Pipe Section,
Mechanical Branch, Design and Construction Division,
Bureau of Reclamation, Denver, Colorado.

PART ONE

LOW winter temperatures prevailing at dams, power plants, pumping plants, and other hydraulic structures located in northern regions, may require the installation of ice-prevention or de-icing systems. Such systems, when operated prior to freezing of the surrounding water, will prevent the formation of surface ice in critical areas or remove ice already formed if operated after freezing. Ice-prevention systems may be used for various purposes, such as protecting dams against ice pressure, keeping flashboards and trashracks free of ice, or eliminating ice from the operating parts of hydraulic control gates.

The Bureau of Reclamation is using two different methods of ice prevention, each with limited application. These are the compressed air, commonly called the " air bubbler system," and the electrical induction heating system. The compressed-air system lends itself best to the prevention of ice along the upstream faces of dams, also at trashracks and gates, while the electrical heating system is used primarily for the prevention of ice along the seats and seals of drum, radial, and slide gates. This article discusses the compressed-air de-icing system and briefly summarizes the electrical heating system.

Ice-prevention systems by means of compressed air have been used in Europe and this country for many years. The first large installation in the United States was made at Keokuk Dam on the Mississippi River. This installation was made after a 20-inch-thick sheet of ice damaged three of the outlet gates. To prevent further damage to these gates, a narrow slot of ice in front of practically every one of the 119 gates was thawed out by steam discharged from a perforated pipe. Following this temporary expedient and some tests with compressed air, the compressed-air de-icing system was adopted during the winter of 1917-18 as a permanent solution of the ice problem for the gate installation. The practical value of the compressed-air method of ice prevention was determined by a series of tests which have proved that the work could be done with a very small amount of air. Consequently a complete compressed-air system was installed at Keokuk Dam.

Theory of Compressed-air De-icing System

In a large body of water that is frozen over, the water temperature increases with increasing depth below the surface, varying from 32° to approximately 39° F, the temperature at which water has its maximum density. With a compressed-air de-icing system, the air is released into the reservoir at strategic points near the structure to be protected from ice, at depths from 10 to 35 ft. below the water surface. The compressed air being discharged into the reservoir from submerged air nozzles breaks into small bubbles and mixes with the surrounding comparatively warm water. The stirring and mixing action of the released air induces a strong upward current of relatively warm water which either melts ice already formed or prevents the formation of new ice. It has been found from experiments that this circulation is effective for an area varying from 12 to 20 ft. in diameter. This influenced the spacing of the air nozzles to provide the required coverage for the system.

Experiments of Compressed-air System

When in 1938 the Bureau of Reclamation decided to provide an ice-prevention system for its Grand Coulee Dam (on the Columbia Basin Project in the state of Washington), a review was made of existing literature on the subject. Although several installations of the compressed-air system of ice prevention were at that time in use both in this country and abroad, information on design and operation was very meagre. Experience with the compressed-air system installed at Keokuk Dam and at other structures, and the experiments made at the Keokuk Dam, however, provided some essential data for the design of the de-icing system at Grand Coulee Dam. It is believed that the de-icing system designed for Grand Coulee was the first one in this country which was installed in a dam during its construction.

When the design of this compressed-air de-icing system was undertaken, problems developed relative to the most favourable size, shape, and direction of discharge of the nozzle orifice. Questions also arose regarding the cooling effect due to the expansion of the air at the orifice exit. As these problems could not be resolved theoretically, laboratory investigations were initiated for their solution. The laboratory investigations included examinations of a number of orifice designs and a detailed study regarding the cooling effect of the expanding air issuing from the orifice. A glass-sided tank was used for the orifice test to make visual inspection possible. The air nozzle was placed at the bottom of the tank and connected to a high-pressure air line having a throttling valve for control. Differential pressures between the air line pressure and the static pressure at the orifice were measured by mercury U-tubes. A number of orifices were tested ranging from cylindrical to tapered holes, also from single to multiple holes. The tests showed that a discharge directed vertically downward has the best flow pattern, the largest cross-sectional area of the rising air current, and the best division of air bubbles. Fig. 1 shows a typical flow pattern from a nozzle having a cylindrical orifice of 0·116 in. diameter.

The discharge capacities of the various orifices were measured with a gas meter of the displacement type. A special insulated tank was constructed for a detailed investigation of the orifices under freezing

conditions. The tank was 12 ft. deep and was provided with 54 ft. of ¾ in. copper tubing in coil form. Thermometers were provided for the temperature measurements and piezometer connections for determining the static pressure at the orifice elevation. Two glass windows were used for visual observation and photographic recording. The orifice to be tested was placed at the end of the copper coil. Before starting a test, the tank was charged with 1,200 pounds of ice. After allowing the water to be cooled, the test was started. Water and air temperatures, air pressure, and the quantity of air discharged were determined. The differential temperature across the orifice was progressively increased until the orifice froze or the pressure limit of the apparatus was reached.

The experiments have shown that orifices having tapered exits develop the best flow pattern. They also have indicated that a discharge of 2 cu. ft. of free air per minute at a differential pressure of 2 lb. per sq. in. is sufficient to induce a strong upward current. As an orifice of the short-tube type with a ⅛ in. cylindrical hole was found to be somewhat superior to the long tapered orifice as far as freezing is concerned, it was adopted for the Grand Coulee Dam de-icing system. The orifice may freeze solidly and stop the flow of air if the initial air and surrounding water temperature is in the range of 32° to 33° F. In the above-described tests no complete freezing was observed when the temperature of the air and the surrounding water was above 33° F. and the differential pressure was within the range available with the laboratory apparatus. Complete freezing may, however, be possible at higher differential pressures.

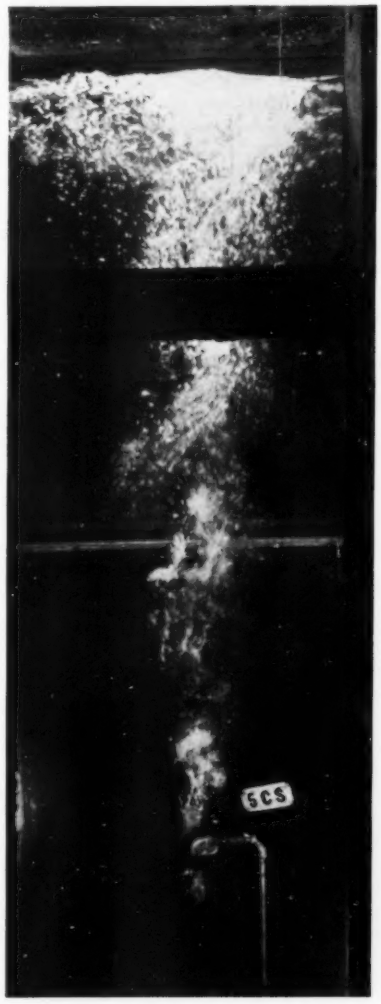


Fig. 1. Flow pattern from 0·116 in. diameter orifice

In addition to above tests, a laboratory experiment was also made to determine the effect of compressed air discharging into a glass tube filled with water representing a 1 in. distribution pipe. The test demonstrated that for pipes 1 in. in diameter and smaller, the water is blown out of the pipe when the de-icing system is placed in operation; and for larger diameters, the air blasts a passage through the water in the pipe.

To obtain information on the intensity of ice pressures against dams and other hydraulic structures, the Bureau of Reclamation conducted experimental investigations between 1947 and 1951 at several reservoirs in Colorado. Ice-pressure measurements were made by means of specially designed indentor gauges and also with electric-resistance-type pressure gauges, which were installed and frozen into holes cut through the ice sheet. It was found that ice pressures are influenced by the nature of the reservoir shore. At steep, rocky shores which offer severe restraint to an expanding ice sheet, generally higher ice pressures develop than at flat and sandy shores. The most extensive investigations were made at Eleven Mile Canon Reservoir, where ice thicknesses from 7 to 20 in. were measured during the winter of 1950. Gauges installed in the vicinity of the dam where the reservoir has a steep and rocky shore, indicated ice pressures varying from 75 to 325 lb. per sq. in. near the top of the ice sheet. Thrusts from 11,000 to 24,000 lb. per linear foot were estimated at these points. The gauges located in the vicinity of gently sloping sandy shores, on the other hand, showed maximum pressures of only 165 lb. per sq. in., and thrusts up to 19,000 lb. per linear foot.

Similar experience was had at other reservoirs having a variety of shore conditions. The greatest thrusts, up to 19,000 lb. per linear foot, were estimated for Tarryall reservoir, which has a steep, rocky shore. At Antero and Shadow Mountain reservoirs, which have flat, sandy shores, the maximum thrust was only 5,800 lb. per linear foot. The temperature of the ice which determines the contraction or expansion of the ice sheet was also measured. While the lower surface of the ice which is in contact with the water is always 32° F., the upper surface, being exposed to the atmosphere and to solar radiation, varies considerably in temperature. To determine this temperature gradient through the thickness of the ice sheet, temperature readings were taken at several depths. The information on ice pressures and thrusts gained during these investigations indicated the advisability of protecting certain hydraulic structures against ice pressures by de-icing systems.

Where a compressed-air system is impracticable, as at operating points of gates, direct heating may be used. To keep the pier plates and seats of the spillway drum gates free of ice at Grand Coulee Dam,

where temperatures as low as 28° F. below zero have been recorded, two different methods of heating were investigated. The first was by means of circulating a liquid; the second by direct electrical heating. In the first method, liquid having a low freezing point was heated by electricity and circulated through pipes embedded in the concrete adjacent to the areas to be heated. By this method, the temperature of the liquid could be maintained below 150° F., the desired maximum temperature for the concrete, by controlling the speed of circulation. Because of the high initial cost of the equipment and installation and the danger of leakage due to corrosion, this system was rejected in favour of the direct electrical heating method. This can be accomplished by either the straight-resistance or the induced-eddy-current method. As a search through the available literature failed to furnish any useful data on the design of this method of ice prevention and as the complexity of the problem made a mathematical solution difficult, experiments were initiated for that purpose.

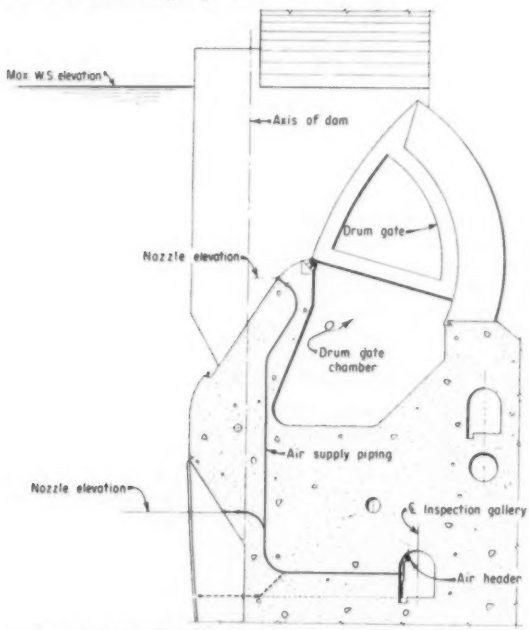


Fig. 2. Air-distribution piping for drum gate

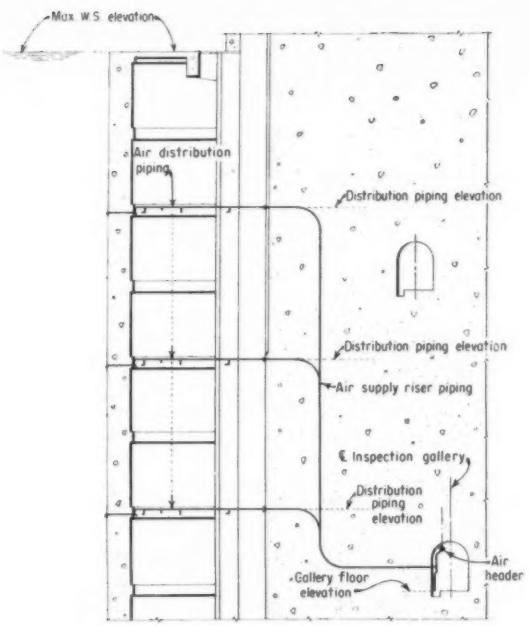


Fig. 3. Air-distribution piping for trashracks

Full size samples of the pier plate were used in the test. Field conditions were simulated by embedding the plate in concrete and tests were conducted to determine operating temperatures. It was found that the required amount of heat (70 watts per sq. ft.) could be obtained by using three No. 1 AWG cables operating in parallel and each carrying approximately 250 amperes. The heat runs revealed that the operating temperature of the cable in the field will be approximately 70° F. when the air temperature is 28° F. below zero.

To protect the concrete from temperatures above the assumed safe maximum of 150° F., thermostats are used which disconnect the transformers when that temperature is exceeded. Thermostats operate the breaker connected to the high tension side of each transformer. Circuit breakers are designed for manual operation, and it is possible to heat the plate on one side of a pier without heating the other plate. The possible temperature differential due to this condition may create special problems in the design of the piers and it may be necessary to add extra reinforcing steel to them.

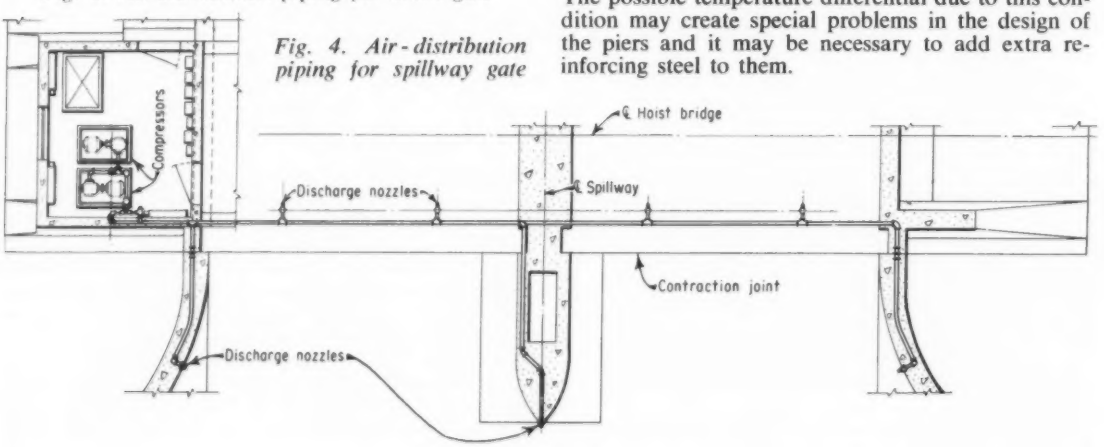


Fig. 4. Air-distribution piping for spillway gate

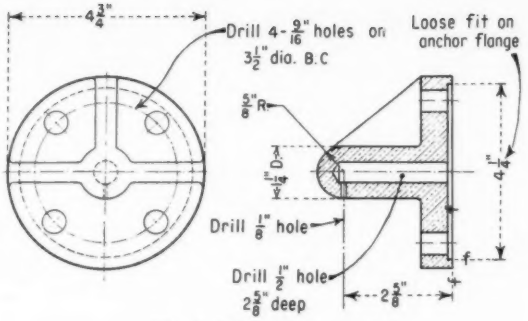


Fig. 5. Flanged air nozzle

Design and Installation of Compressed-air De-icing System

A compressed-air system should be designed to furnish an adequate supply of dry air at the required pressure to critical areas of the structure to be protected. An analysis should be made of each structure to determine the required coverage, air nozzle locations, and the arrangement of piping and control stations. The system generally includes two air compressors as alternate sources of supply, a supply line or air header to convey the air to the structure or structures to be protected, a distribution system to distribute the air at strategic points of the area to be freed of ice, and one or more control stations, each with a series of valves to control the air discharge. As most reservoir levels are subject to considerable fluctuation during the winter months, the air distribution piping should be installed at an elevation to accommodate these varying water levels. For most efficient operation the air preferably should be discharged at depths ranging between 10 and 35 feet below the water surface. To maintain this range for very large reservoir fluctuations, it may be necessary to install distribution pipes at two or more levels. At Grand Coulee Dam, where a winter fluctuation of approximately 80 ft. was anticipated in the reservoir surface, three sets of distribution pipes were installed at different levels for the trashracks to serve the fluctuating water surface.

Hungry Horse Dam, a Bureau structure in the state of Montana, having a reservoir surface fluctuation of over 200 ft., was provided with four sets of air distribution pipes to accommodate all reservoir levels between the high and low mark. With the exception of the Grand Coulee and Hungry Horse Dam installations, all compressed-air systems so far installed by the Bureau were designed for operation at one level only. Of the 15 installations made to date, all except one were built into the dam during construction as an integral part of the structure. The one exception is the Bureau's Black Canyon Dam on the Boise project in Idaho, which initially was not provided with a de-icing system. The ice difficulties developed during operation at the spillway drum gates and ice pressures prevailing against the upstream face of the dam made a de-icing system desirable. Before the de-icing system was installed, it was necessary to keep the water surface 5 ft. below the maximum level to prevent overstressing the dam by ice pressure.

As mentioned above, structures to be provided with compressed-air de-icing systems should be analysed thoroughly to determine the most advantageous location of the air discharge nozzles. The nozzles should be spaced preferably not over 10 ft. apart. This will provide an effective circular area of about 12 ft. diameter with a differential air pressure across the nozzle of 2 lb. per sq. in. as confirmed by experience and experiments made by the Bureau of Reclamation. In drum gate installations the discharge nozzles should be placed near the hinge of the drum gate in the cantilever wall of the gate chamber for protection of the drum gate. Discharge nozzles should be provided also at a minimum depth of 10 ft. below the bottom of the drum gate chamber, as shown in Fig. 2, to protect the cantilever wall against ice pressure. The air distribution piping for the trashracks of the Grand Coulee penstocks is shown in Fig. 3. Identical piping is installed on three levels to accommodate the varying water surface elevations in the reservoir. For de-icing installations of spillways, the discharge

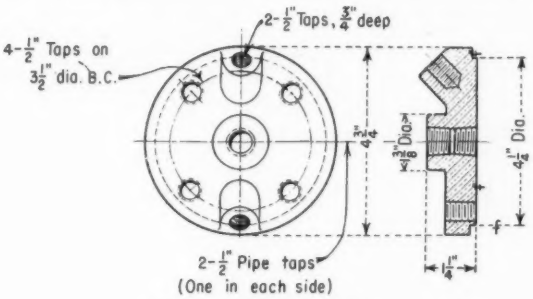


Fig. 6. Anchor flange

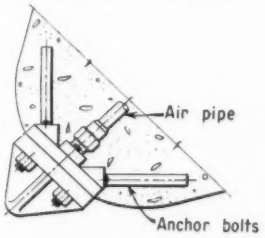


Fig. 7. Flanged air-nozzle installation

nozzles should be located not less than 6 ft. upstream from the face of the gates, as shown in Fig. 4.

There are two types of nozzles which have found general use in compressed-air systems designed by the Bureau of Reclamation. Fig. 5 shows an air nozzle which was specially developed for use on trashrack and spillway walls or other places where rugged construction is required to prevent damage from floating debris. This nozzle is shaped to discharge the air away from the wall. It is made of cast bronze and consists of a flange and a projecting hub with central core into which a $\frac{1}{8}$ in. orifice is drilled. When installing the nozzle, the orifice should be directed downward. Installation is by means of a special bronze anchor flange shown in Fig. 6, to which the nozzle is attached with four cap screws or stud bolts. The anchor flange is connected to the distribution pipe and is concreted into the structure, being fixed in place with two anchor bolts. Fig. 7 shows a typical installation of such an anchor flange and air nozzle. When discharging air into protected areas where

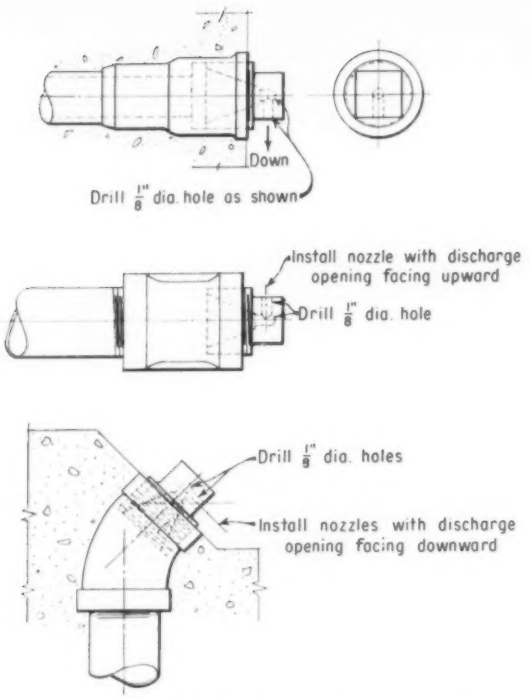

Down
Drill 1/8" dia. hole as shown
Install nozzle with discharge opening facing upward
Drill 1/8" dia. hole
Drill 1/8" dia. holes
Install nozzles with discharge opening facing downward

Fig. 8. Typical plug-type air nozzles

nozzles are safeguarded against damage, a nozzle consisting of a standard bronze pipe plug may be used, into which a $\frac{1}{8}$ in. orifice is drilled. Depending on the direction of air discharge desired, the orifice may be pointed up or down or in any other direction by turning the plug in the fitting accordingly. Fig. 8 shows some typical installations of these plug-type air nozzles.

If installed in a structure during its construction, the air distribution piping should preferably be embedded in concrete. Copper tubing with solder-joint fittings is generally used for the embedded portions of the piping. Long radius bends should be provided in the distribution lines to facilitate cleaning operations when necessary. Fig. 9 shows a typical distribution piping assembly for a large penstock trash-

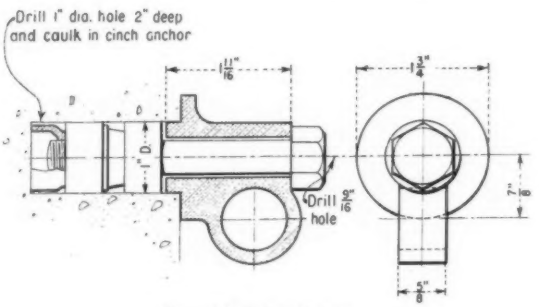


Fig. 10. Pipe hanger

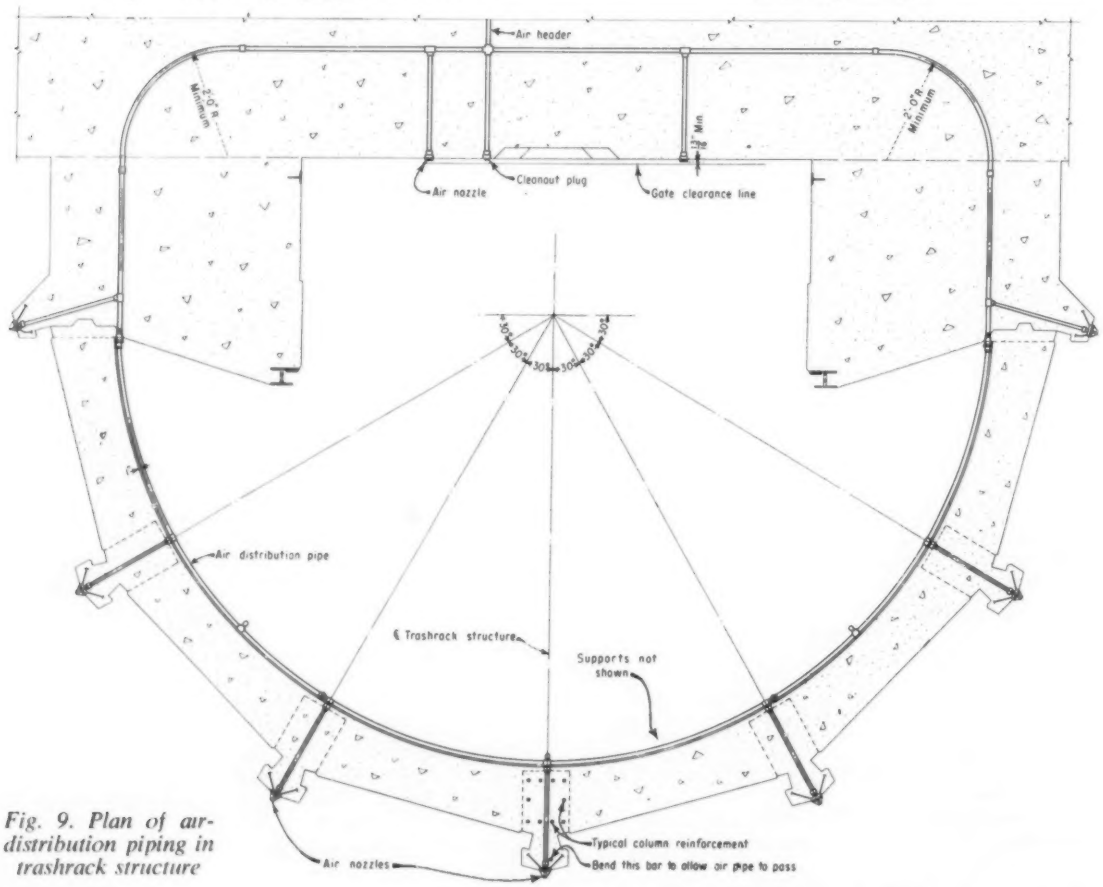


Fig. 9. Plan of air-distribution piping in trashrack structure

rack structure. The inner portion of the piping near the dam is embedded in concrete and the outer portion is installed inside the semicircular wall of the structure. This exposed piping is supported with bronze pipe hangers (Fig. 10) fastened to the concrete

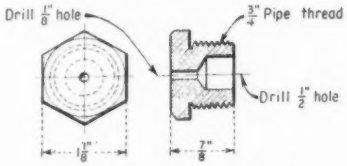


Fig. 11. Special air nozzle

by means of cinch anchors. Short branch pipes lead from the distribution piping to the air nozzles. The nozzles are distributed on both the inside and outside of the trashrack structure. On the inside, nozzles of a special design are used as shown in Fig. 11, and on the pier noses outside the structure, the flanged air nozzles shown in Fig. 5 are used.

Dependent on the required air supply, copper tubes from ½ to 2 in. diameter were used as the distribution pipe for the various installations. The copper pipe is made from Type K hard copper conforming to Federal Specification WW-T-799. A light anneal may be used in making the bends, as it is expected that the work-hardening produced by the bending operation will restore approximately the initial hardness of the copper. The solder-joint fittings used are of a cast bronze alloy containing about 85 per cent. copper, and 5 per cent. each of tin, zinc, and lead. All joints for copper connections should be properly sized and finished for capillary-type solder joints and should be air tested under water at 90 lb. per sq. in. gauge pressure. The bends are usually fabricated in

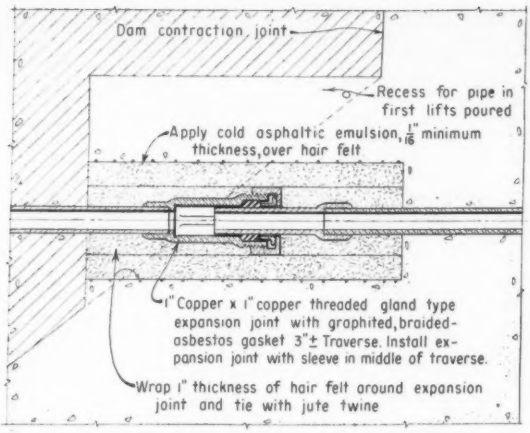

Dam contraction joint
Recess for pipe in first lifts poured
Apply cold asphaltic emulsion, 1/16" minimum thickness, over hair felt
1" Copper x 1" copper threaded gland type expansion joint with graphited, braided-asbestos gasket 3" ± Traverse. Install expansion joint with sleeve in middle of traverse.
Wrap 1" thickness of hair felt around expansion joint and tie with jute twine

Fig. 12. Expansion joint for air pipe

the shop ready for installation in the structure. During installation, precautions should be taken to prevent damage to the copper tubing. The embedded portions of the distribution piping should be held under pressure while concreting and grouting operations are in progress. Solder joints should be made in a conventional manner to provide an airtight pipe system. Expansion joints should be provided for pipes running across contraction joints of concrete dams or other concrete structures. These expansion joints absorb differential movements between adjoining concrete blocks. Fig. 12 shows a typical expansion joint, which must be installed prior to concrete placement, being protected from the concrete by a 1 in. layer of hair felt.

(To be continued)

Fifth Congress on Large Dams

The Fifth Congress of the International Commission on Large Dams, which is affiliated to the World Power Conference, will open at Paris on May 31, 1955. After about a week devoted to technical sessions there will be a study tour in France and North Africa. The following is the technical programme of this Congress :

Question No. 16: Design and Construction of Dams on Permeable Soils and Methods of Foundation Treatment.

Question No. 17: Economic and Safety of Different Types of Concrete Dams.

Question No. 18: Settlement of Dams due to Compressibility of the Dams Materials or of the Foundation Soil, Including Earthquake Problems.

Question No. 19: The Relation of the Cement Content of the Concrete to Performance in Practice of (a) Gravity Dams (Interior and Exterior), (b) Arch Dams, (c) Buttress Dams, and its Influence on Permeability and Frost Resistance.

(The numbering of the Questions is consecutive with the numbering of the Questions discussed at previous Congresses.)

Offers of papers within the scope of one or other of Questions 16 to 19 are invited from engineers in Great Britain for submission by the British National Committee. Such offers should be sent as soon as possible to The Secretary, British National Committee on Large Dams, 201-2, Grand Buildings, Trafalgar Square, London, W.C.2.

In accordance with the Congress regulations, papers must be ready for despatch by the British National Committee on Large Dams so that they reach the Central Office of the International Commission on Large Dams in Paris not later than September 1, 1954. The name and address of the author, the title of the paper and the approximate size of the contribution should be submitted to the Secretary not later than May 31, 1954.

Gear Units for British Guiana. David Brown and Sons (Huddersfield) Ltd. have received an order from Gilbert Gilkes and Gordon Ltd. for two sets of combined helical and bevel increasing gear units, which will be incorporated in water-turbine plant under construction at Tumatumari Falls, British Guiana. An interesting feature of the units, which are designed to transmit 1,100 h.p. continuously at 104/1,000 r.p.m. is that they have vertical input and horizontal output shafts. Each helical gear is of 40 in. centres and 16 in. facewidth, while the spiral bevel gears each have a 6 in. face, with 19 in. cone distance. The units are fitted with roller bearings throughout, have forced lubrication systems and are enclosed in fabricated cases.

Fig. 1. Distant view of the Bawgata catchment

A Preliminary Survey in Burma

E. A. Logan, M.Sc., M.I.C.E., M.I.Mech.E., M.I.E.E., gives an account of a preliminary survey of the Bawgata Valley carried out when he was secretary to the Hydro-Electric Survey Board and chief electrical engineer and manager to the Burmese Government. Further work was interrupted by civil disorder, but this article gives a vivid picture of pioneer work in the tropics.

THE possibility of developing hydro-electric power in Burma has appeared attractive for the last half century but the scale of development is small in comparison with the potentialities. The solution of the problems involved continues to be intractable. The attractiveness arises from the existence of a ring of hills with heavy rainfall around the populated central plain, and the difficulty, from the seasonal character of the rainfall and the relatively long distances of the power sites from the centres of population.

Burma was administered from India until 1937 and secured independence in 1947. A great mass of data on catchment areas and water storage sites was accumulated through the personnel of the India Civil Service and later of the Burma Civil Service, with the object of applying the knowledge to irrigation and power development. Notable contributions to the hydro-electric survey of Burma were made by Raikes, Meares, Nimmo and Eades. Some hydro-power was developed and utilised privately by such mining undertakings as the Mawchi Mines, The Burma Corporation and the Anglo-Burma Tin Company. In only one instance was hydro-electric power used for a public supply of electricity and that was at Maymyo.

Considering the enormous potential power in the hill areas it may appear strange that there has been so little development. The explanation lies largely in the economic state of the country. Large enterprises have been financed by outside capital and owing to the general lack of security in the military sense, have been located in compact areas over which the investor could maintain control. A hydro-electric power development with its associated transmission spreads over several hundreds of miles and is inherently difficult to control and maintain. Local financiers prefer schemes showing large immediate profits, and the initially unremunerative nature of hydro-development and the low rate of return is not considered attractive.

During the period of the Japanese occupation, when

the Government of Burma was transferred to Simla, a great deal of careful thought was given to the future rehabilitation of Burma. The possibility of establishing new industries there was considered under the chairmanship of U Kyaw Min, LI.B. (Cantab.), who then wrote regarding industrial expansion:—

"I am assuming (as a prerequisite for the establishment of industry) the supply of cheap electric power even in rural areas and that the decision will have been made before we return to Burma to get on with a hydro-electric scheme for Burma and that it will be put into operation at the very earliest opportunity. Even without the prospect of any further industrialisation in Burma, I consider that sufficient justification has been made out for the harnessing of the water power that is available in Burma, but without electrification of the country I see no scope for any industrialisation. In the past, 17,000 kW of hydro-electric power were used in industry, mainly for mining operations. We have accurate reports of sites capable of giving 400,000 kW while many potential sites have not yet been investigated. It appears that Burma is very favourably placed in respect of hydro-electric power.

"We are spending over 50 lakhs of rupees every year on the importation of over 300,000 tons of coal from India and there can be no excuse for not getting a move on with a hydro-electric scheme. I am assuming, therefore, that we shall have cheap power for industrial development. Electricity for everyone should be our slogan. Cheap power is a *sine qua non* for our industries . . . The persons who veto the proposed hydro-electric scheme, or who perpetuate in any way the necessity for any substantive importation of coal will have much to account for on Judgement Day."

Initiation of Proposal for the Supply of Hydro-Electric Power to Rangoon

The largest population group and potential industrial area in Burma is the capital city of Rangoon. This town, however, is situated in the approximate centre of a level alluvial area and the nearest practicable potential water-power development is 125 miles to the north-east.

In 1927, Messrs. Rendel, Palmer and Tritton prepared a report on the development of the Pyagawpu and Yunzalin Rivers for the supply of water and hydro-electric power to Rangoon. At this time the need for an increased supply of domestic water was paramount and the question of development and transmission of power a secondary consideration. The water-supply problem was later adequately solved by other means but the need for electrical power increased. A reconsideration of the scheme, unbiased by the question of water supply, revealed most attractive hydro-electric potentialities.

After consideration of alternatives, it was recommended that the preferred scheme was to develop a storage basin above the Bawgata Chaung (Chaung= River) with a series of power stations located sequentially downstream (see Fig. 3), utilising the points

Fig. 2. View of the river bed showing the bed rocks. The block of granite in the foreground is deeply scored by water erosion supplemented by abrasion due to water-borne bamboo debris

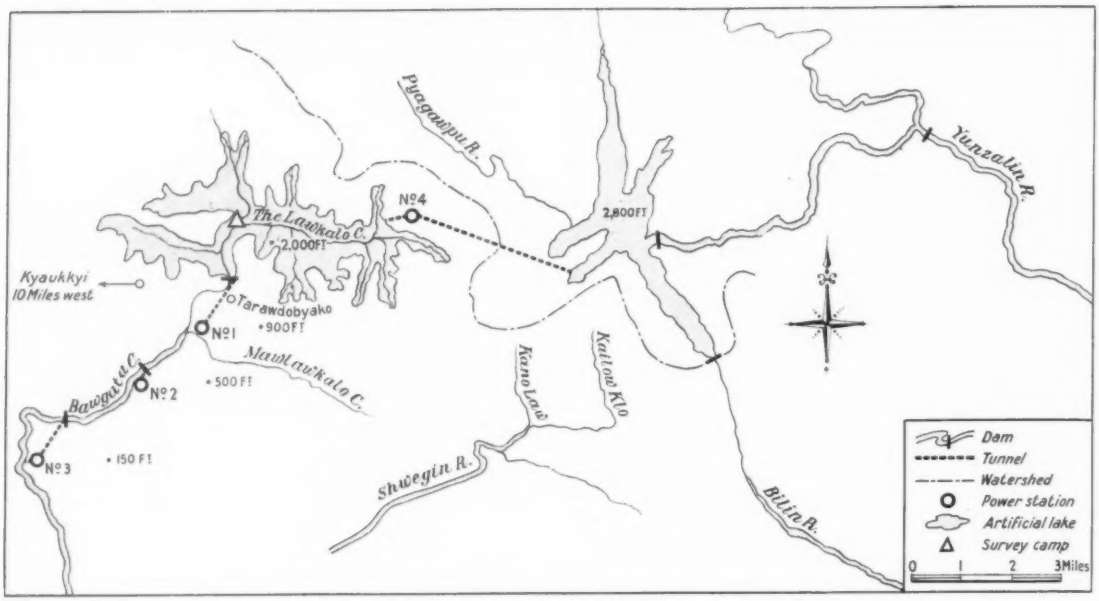


Fig. 3. Locality map of proposed development on the Bawgata

of greater concentration of change of level for this purpose.

The catchment area to be developed initially was relatively small, but the seasonal rainfall of approximately 100 in. was high. For subsequent development, it was proposed to divert water from an adjacent valley, Pyagawpu, and later again, to dam the Yunzalin River and return water from the Yunzalin catchment area back along the original outfall of the Pyagawpu. It was realised that the later developments might involve complicated civil-engineering works and pumping of water, but against this no extension of the electrical transmsission would be involved and the possible utilisation of the generating plant could be greatly extended by improvement of the load factor.

Development of Power in Bawgata Chaung

Above Bawgata Chaung, there is an extensive relatively level area (Thelawkalo Chaung). The outfall from this area flows through a narrow defile, and below this point the river bed falls sharply to a point where the Mawlawkalo Chaung joins the Bawgata Chaung. From examination of maps, it was deemed to be relatively easy to dam this defile. This assumed good geological conditions, and the narrow nature of the defile argued that possibility. Roads existed to within ten miles of the proposed power-station site.

Subsequent Development

The Bawgata Chaung may be dammed at two points lower down, and with the initial installation of a 10,000 kW generator at each point the power generation can be doubled. When more water is needed, the water from Pyagawpu Valley may be brought in by a tunnel through the watershed, with a fourth power house sited at the outlet of the tunnel. Later the waters of Yunzalin Valley may be raised by pumping through a relatively low head and also be brought through this tunnel.

Design Criteria

In giving consideration to the competing schemes, due weight was accorded to the following factors:—

1. Speed of development.
2. Ease of access.
3. Nearness to Rangoon.
4. Cheapness in first cost.
5. Ability to develop the power at the least number of points (i.e. fewer power stations and dams).
6. Avoidance, in the early stages at least, of a large

Fig. 4. Doctoring a sick elephant

Fig. 5. Suspension bridge constructed entirely of bamboo

amount of tunnel work.
7. Economy in use of imported materials.
8. Avoidance of long roads through jungle or hill country.

Outline of Scheme and Basis of Initial Power Estimates

1. To establish an artificial lake in the marshy area 14 miles east of Kaukkyi, by damming the defile, ¼ mile north of Takawdobyako, with a resulting catchment area of 48 sq. miles.
2. The rainfall in this area is known to be between the limits of 140 and 80 in. per annum. Taking a conservative figure of 100 in. assuming that no exceptionally low rainfall will be experienced during the development years, with 50 per cent. run-off, the average flow is 177 cusecs.
3. The artificial lake area is estimated at 4·5 sq. miles and the variation of level to give three months' flow is 11 ft.
4. The dam crest level is estimated to be 2,000 O.D. with a crest length of 440 yards and a height at the centre of 180 ft.
5. The available head for the first stage of power development would be between the 2,000 ft. and 900 ft. contours. This gives a possible continuous power available all the year from this first development of 10,600 kW.
6. Power transmission would be at 132 kV by means of a double-circuit line taken along the north-west side of the Bawgata Chaung.
7. It will be necessary to construct 10 miles of road to join the Shwegyin-Kaukkyi road and to improve a total of 30 miles of road to bear heavy motor transport. Allowance is necessary for the strengthening or rebuilding of 20 road bridges and it may be an advantage, during construction, to have a second road on the south-east side of the Chaung and one-way traffic along both sides.
8. Additional power may be developed by damming the narrow valley at Bawgata Chaung.
9. At a further stage of development, water from Pyagawpu Valley may be brought into the upper reaches of the Bawgata Valley by means of a tunnel approximately 3 miles long. Later still, the Yunzalin River may be diverted into the Pyagawpu Valley and the whole of the waters of the Yunzalin catchment area fed into the Bawgata Valley.

When this is done, the total minimum annual cusecs are estimated to be:—

1. At Pyagawpu tunnel (probably extremely conservative)	330 cusecs
2. At Bawgata outlet an addition for the Bawgata catchment	177 cusecs
	507 cusecs

The total average power possible through the year is estimated to be: at Pyagawpu, 13,200 kW; at the storage lake outlet, 30,420 kW; and at Bawgata Chaung outlet, 20,280 kW; giving a total continuous power of 63,900 kW. The estimated peak power, on a conservative basis, possible from this scheme is of the order of 120,000 kW with a load factor of 50 per cent.

Altogether, the scheme from the point of view of power supply to Rangoon was one of great attractiveness. It represented the nearest power site, and the

power could be developed by successive additions of 10,000 kW sets with very approximately level additions of civil work necessary to bring each successive new set into effective operation.

Establishment of Hydro-Electric Survey Board for Burma

The Government of Burma expressed a desire to extend the industrialisation of the country. Various *ad hoc* bodies were established to this end, including the setting up of the Hydro-Electric Survey Board, by the Hydro-Electric Survey Order, 1947, which established the powers of the Board and voted the necessary initial funds to enable the work to be carried out. Burma secured independence on January 4, 1948.

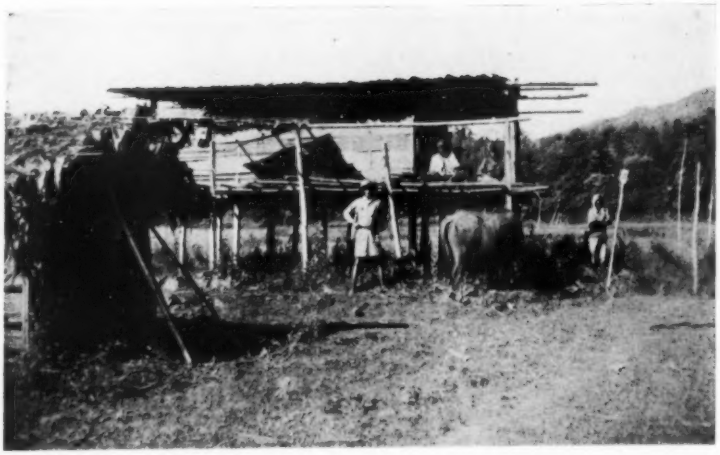


Fig. 6. A Karen bamboo house in the pondage area

Reconnaisance Survey

All the foregoing outlines of the scheme having been deduced from a study of maps, the report of the consulting engineers for the water-supply scheme for Rangoon and other available sources, and the proposals having been submitted to and agreed by the Hydro-Electric Survey Board, plans were made for a reconnaissance survey to be made in the dry season of 1947.

A party was assembled at Rangoon consisting of the author, then Secretary to the Board and Chief Electrical Engineer and Manager to the Government, Mr. I. Walker, O.B.E., Adviser to the Board, U Pu, B.Sc.(Lond.), Geologist and Mining Adviser to the Government, and Dr. U Ohn Pe, Government Malariologist.

Prior enquiry had been made as to the state of roads and also of the river crossings. It was intended to establish base headquarters for stores, office and communications purposes at Kaukkyi, a small town which lay some 14 miles to the east of Penwegon, a larger town situated on the main Rangoon-Mandalay road and railway. General information was that the main road to Penwegon was in good condition, that the road from Penwegon to the River Sittang was in fair condition, that the ferry was crossing the river and that the road from the ferry was dry enough to take traffic. So far as the security situation was concerned, there had recently been no fighting in the area and there were no reports of insurgents being present. In spite of this latter report, it was deemed advisable to secure a guard of some twenty armed Burma Police to be at the disposal of the Survey.

The main stores were sent ahead with the storekeeper in three ex-army four-wheel-drive lorries. It was found possible to get only one of these transported across by the ferry, but this sufficed for immediate needs as this one vehicle was able to shuttle transport the loads of the other two vehicles along the remaining five miles of roadway.

Until the ferry was reached the journey to Kaukkyi by the main survey party was a completely uneventful motor journey over comparatively good roads. The road ended abruptly at the river bank and was replaced by a track deeply cut into alluvial silt, from the high-water mark of the flood season to the lower-water level of the swiftly running Sittang, at this point some half-mile wide. The ferry consisted of a timber platform supported on two country boats which were restrained from being swept away by the current by a steel wire strained across the river. The motive power for the ferry was man-operated sweeps, although it appeared possible that the current of the water could usefully have been applied to this purpose.

With difficulty and considerable risk, one station wagon was manoeuvred on to the ferry, which it completely dominated, but a successful crossing was made and the vehicle was brought up the bank at the far side partly by its own power, but chiefly manhandled, to the road. The journey from the ferry to Kaukkyi quickly corrected any impression that valuable days had been lost since the end of the rainy season, by allowing too long a period to elapse to permit the roads to dry out. It was several times necessary to by-pass the lower parts of the road bed to avoid deep mud runs which even at that date would have bogged the car down.

At Kaukkyi, the Circuit House was requisitioned as a base. Local headmen were interviewed and plans discussed. It was clear from the mixture of languages employed by the interpreter that quite a few interests were involved. Arrangements were made to take along, in addition to the interpreter, an aged local notability who was reputed to have considerable influence with the hillmen and who promised to use his influence to secure their co-operation. He later proved as good as his word.

Two or three days were spent at this base in making up loads, arranging for porters and elephants and in satisfying local curiosity. This latter was most important since it was essential that information of the survey should extend into the hills in advance of the party and that a favourable viewpoint should be established. All these arrangements proceeded, as it seemed, all too slowly and it took all the energy and patience of the party leaders to maintain progress towards a start.

An Indian cook was taken to provide meals for the leaders, and although the cooking arrangements were primitive in the extreme, the quality and variety of the meals remained at an unvarying high level. The

services of such a man on a survey are valuable, as a means of maintaining morale and avoiding dysentery.

At a final conference with the representatives of local interests on the evening preceding the commencement of the trek, final routes, duration and extent of the penetration into the hill country were discussed, with the greatest of frankness. Opinion was divided as to the need for armed support and it was decided to leave half the force at Kaukkyi and to take only ten armed police on the actual survey. On this survey the party met with no violence. Had there been any armed opposition, it does not seem that the ten police could have been much protection, as later events were to reveal.

It was intended to travel to the storage site by a trade footpath, camp in the storage area for about seven days and return to Kaukkyi by another route which would embrace the dam site and the headworks for the first power station. The scale of rations

Fig. 7. Three Karen boys and an Indian labourer

was worked out on the basis of the survey being self-supporting during the whole of the fourteen days. It was hoped that by using elephants, which are capable of feeding on bamboo and therefore self-supporting so far as food is concerned, to reduce the number of human porters. The available elephants proved to be not in very good condition and the loads they carried were disappointing, about the equivalent of six porters.

The utmost difficulty was experienced in lining up the porters on the following morning. Fortunately, there was a roughly fenced compound around the Circuit House, and in due course porters were separated from spectators, ranged at approximately equal spaces and loads apportioned. Rolls of hessian cloth had formed part of the stores brought forward and a length of this was issued to each man to wrap his load. Methods of carrying were various. Some divided their loads and hung the two halves, Chinese coolie fashion, at each end of a bamboo pole. Others hefted the bundle over their shoulder, and some joined with others and supported their joint burden on a pole carried between them. After checking the weights of their loads and that all necessary stores were being sent forward, the procession started. Pictures of Livingstone and Stanley represent their porters striding through the jungle in single line ahead, with uniform loads carried with military precision. These particular porters defied all attempts at uniformity and precision. They just disappeared up the trail in their own fashion and at their own pace. Nevertheless, two days later, at the point chosen for a camp site, every article entrusted to them was correctly accounted for.

There were other surprises. The track almost invariably followed the line of the watersheds and consistently rejected the easier contour lines. A possible explanation is that such a track would offer the greatest possibility of remaining passable in the wet season. Also, of course, it meant a great deal of ascending and descending of sharp hills, and several months previously spent at an office desk in Rangoon was poor training for this. The path was closely walled by tall bamboos, and as a result nothing at all of the surrounding country could be seen. This feature was later to prove a great handicap in making surveys, since all sight lines had to be cleared with great expenditure of labour.

The transit camp for the first night was established on a clearing only a few yards in extent on a ridge sloping away like the roof of a house. The porters threatened to strike and return to base because there was only plain rice, no dried fish and no salt. Promises that these would be available the following day restored calm. The survey leaders were more fortunate. The cook produced, with complete nonchalance only half an hour after the halt, soup, curried eggs, sweet and coffee. Throughout the whole survey he never departed from the same high standard he maintained in Rangoon, however difficult the conditions. The first day of travel advanced the party only ten miles, but a similar distance was covered before early afternoon the following day and camp was established in the storage area before dark. It was learned on the march that elephants travel more slowly than foot porters, but that a path only a foot wide is sufficient. They can climb what amounts to a series of steps up a steep incline, testing each step with their trunk and gradually transferring weight to a foot with the greatest caution. Due to the low energy content of the bamboo they consume as food, it is necessary for them to feed

Fig. 8. Preparing to strike camp

continually all the time they are on the move and at night they crash around in the jungle surrounding the camp feeding all the while.

Although tentage had been provided for the whole force, it was not found possible to provide transport for tents other than those required by the leaders of the party. There were no complaints from the porters, who evidently expected to make their own arrangements. At each camping point they quickly erected bamboo shelters entirely adequate for their needs. They also provided a table and benches and a roof of the same material and this formed an excellent dining room and office for the leaders of the expedition during the first week of the static camp.

By chance, this camp was located on one of the trade routes and most days parties of hill tribesmen would pass carrying goods for the market of Kaukkyi They did the journey in one day, which had taken us two. This was a convenience, since written messages could be passed back by them and these messages were meticulously delivered.

The purpose of the camp in the proposed storage basin was to collect data as to the reliability of the map concerning the configuration of the area, to ascertain the approximate population and their sources of livelihood, the strength of the rim of the basin, both as regards mass of material and geological formation and to form an opinion as to whether the area, if dammed at the proposed point, would be soundly watertight.

Each day, specialist enquiries were pushed as far as practicable and notes compared each evening. It became known that the doctor was prepared to receive patients and each night his "surgery" attracted a queue of patients drawn from the surrounding hills. They expressed their gratitude by assurances of goodwill and by gifts of food, the latter making welcome additions to the otherwise carefully rationed food carried in. Information was also gleaned about flood levels and high and low river flows. Some dry-weather gauging was done to check the estimated dry-weather flow, with remarkably good agreement with the anticipated figure.

At the end of a week, which was all the time which could be allowed for this static camp, the return journey to embrace the position of the dam site and the upper power station was commenced. No attempt was made on this initial survey to ascertain whether the connecting of the Pyagawpu River with the Bawgata River by tunnel was a possibility, or further, whether it would be practicable to bring in the waters of the Yunzalin at a later stage. It was deemed enough of a task to explore the possibilities of the Bawgata River and for the time being to accept the Yunzalin scheme to be substantially as reported earlier.

From an examination of the map, the easiest route to the dam site would appear to be to follow from the camp site, downstream, for a matter of only two miles. This apparently should have been a simple undertaking. The stream was wide and shallow and the bottom for the most part sandy. Walking along the bed was easy and in fact, pleasant, for the first mile. The jungle on either side was dense and not worth the effort, at this stage, of attempting to penetrate. On the first tentative exploration the party nearly walked on to a sleeping python. It showed no alarm and one of the guides sought permission to attack it and secure the skin. He was dissuaded as we were not there for hunting, but we were assured that it was not a particularly dangerous undertaking for a skilled man to attack such a snake if others were there to assist if he fell into difficulties. By choice we carried no firearms as it had been deemed that these could be a source of provocation to the local inhabitants. We passed by on the other side.

It soon appeared that this easy travel down the river was not to continue, as the bed broke up into into a series of rapids and the rocks became more rugged and finally, to all practical purposes, impassable. Parties, however, were pushed along this route to see if the difficult spots could be bypassed, but in spite of much bamboo cutting, these efforts met with no success in the time available.

There was a well-mapped trade footway which passed behind an intervening hill and this fortunately approached the course of the river near to the point chosen for the dam site. On the map no track was shown between the footway and the river, but as it happened, one was found and brought the party on to the river where it passed through a defile some quarter of a mile below the point it was desired to inspect. It was evident that the track had been established for military purposes by the British or the Japs during the period of the Japanese occupation. There was also a magnificent bamboo suspension bridge spanning the river, about fifty yards long. We could not ascertain by whom it was built, or why, but it was a perfect piece of engineering and there was absolutely nothing other than bamboo used in its construction.

By a fortunate circumstance, one of the side slopes of the possible dam position had been denuded of bamboo for cultivation purposes—the local method being to burn off a strip of hillside, on which crops are then planted for two seasons at the most, after which a fresh area is selected. Not more than a minute percentage of jungle is occupied by this form of cultivation at any one time. The party clambered all over the area, probing and exploring, all thoroughly delighted that the configuration was much as the map indicated, that the ground appeared sound and that the base of the river bed was clean, hard rock. Camp was established that night at a point as near as possible to the projected power station site, and with an early start the following morning it was hoped to make a full inspection of the site, and possibly also some of the run for the headworks.

This proved more than optimistic. In the event, the most serious departures were found between the local topography and the map. A stream shown as straight in actuality followed an S bend. Attempts to follow the stream proved difficult and dangerous. The bed consisted of a waterworn red granite which was as smooth as ice and as slippery. A series of bone-jarring falls and duckings made an overland attempt preferable. This meant one man going ahead and cutting a way through between the close-growing bamboo stalks with a native dah. This was hard work and the man had to be changed at frequent intervals. At times the way was virtually a tunnel through the tangled growth. The most difficult part of the journey was where there were matted layers of old bamboo, springy and unsafe, with unplumbed spaces below. It was not easy to follow men barefooted and spare of build who had spent their lives under just such conditions. The distance to be travelled was no more

than two miles, but after five hours of intense forward pressure, the first objective, the main river, had not been reached. The time was rapidly approaching when a decision had to be made whether to continue forward with a risk of being benighted in the jungle with no food, shelter or adequate means of defence, or to return with the mission uncompleted. Darkness, sudden and complete could be expected about six o'clock. The extent to which forward progress could be safely continued after the mid time available depended upon an estimate of the speeds of the forward and return journeys. It seemed impossible to guarantee finding the identical way back, which would permit the cut path to be utilised for the return journey. The map, having been proved unreliable, was little help at this point. There was hope all the time that a clear view of the river would be round each bend. A decision was taken to press on. Approaching mid afternoon, a magnificent cascade was finally reached. This was our immediate journey's end. Photographs were taken, rocks sampled and as much information gained as time permitted. This was the first open space reached that day and opportunity was taken to have a late lunch. In the late afternoon, the return journey started. Suggestions of short cuts home were firmly resisted and by insistence on the precise way-in being retraversed for the return journey, camp was reached about an hour after darkness set in. Certainly in that last hour it was only the guides who saw the way. The rest only followed and trusted blindly. The two following days brought the party safely back to Kaukkyi, and opportunity was taken on the way to assess sources of building material for roads and dams.

From the information collected by the specialists on this initial survey, a report was prepared and presented to the Hydro-Electric Survey Board, and a decision was given by the Board to continue with more detailed surveys.

Under the direction of U Aye, then appointed as Survey Engineer, the construction of a motor road was commenced between Kaukkyi and the storage basin, and also the work of transferring levels between a bench mark on the Sittang embankment and the storage-basin camp site. This involved driving a line through jungle for 30 miles across a maximum elevation of nearly 4,500 ft. O.D., to a final level at the floor of the basin of 1,920 ft. O.D. To this extent, there was close agreement with the original map.

Plans were also made for an aerial contour survey of the area. At this stage, the total labour force involved for clearing and making roads, handling stores and preparing sites for all-season river gauging exceeded 400 men.

Later, U Aye reported that at four o'clock on the morning of January 31, 1949, survey staff at the camp at the storage basin were awakened by a rifle shot. This was the signal for a heavy attack by insurgent forces. Previous to this incident the camp was a scene of peace and tranquillity set in a remote and picturesque valley. The survey staff were under canvas and in this one-sided engagement it is remarkable that only one life was lost, that of Mr. Gurmukh Singh, one of the instrument surveyors. The remainder of the party made their several ways back to Kaukkyi, which itself had been seized on January 27. The whole party were sequestered in Kaukkyi, unable to make their way back to Rangoon. Their plight was a difficult one. They had no money or stores and only the clothes they had escaped with. While in Kaukkyi, they were in no immediate danger and even given assistance and allowed freedom. The country to the west was occupied by other insurgent forces under separate command of a more extreme nature, who would not hesitate to kill on sight. After considerable adventures and hardship, having lost all his kit, Mr. Walker was able to reach Toungoo and Taungyi, later flying from Heho airstrip, over the insurgent-held area, to Rangoon, reaching this town on June 28.

The Hydro-Electric Survey Engineer, U Aye, travelled via the Sittang River, by Madauk, Waw and Pegu to Rangoon and arrived on June 20. One group went to Papun, then across to Siam and Bangkok before being able to return to Rangoon.

To the physical difficulties of this preliminary survey were thus added the greater trials of civil disorder. The need of Burma and Rangoon for the benefits which the development of this potential source of power can bring are great, and it is to be hoped that this work will one day be resumed in happier circumstances and brought to a successful conclusion.

Quebec Orders Four 150,000 h.p. Turbines and Alternators. A contract for four hydraulic turbines, having what is believed to be the largest individual electric power output of any turbines of their kind yet built, has been placed by the Quebec Hydro-Electric Commission with the English Electric Company of Canada Limited. The turbines are for the Commission's Lac Casse (Bersimis) development on the north shore of the St. Lawrence River, some 70 miles north of Forestville down river from Quebec. The Bersimis river will be dammed and the water will flow from an artificial lake some nine miles through a tunnel to an underground power plant. Ultimately, the station will house eight units. The project is designed to meet the Province's increasing demand for industrial power. It will be one of the outstanding developments in the country.

The turbines are designed to develop a rated output of 150,000 b.h.p. at 277 r.p.m. under a net head of 785 ft. Each machine will be capable of developing 175,000 b.h.p. under a maximum net head of 875 ft.

The basic development and engineering are being done by the Hydraulic Department of the English Electric Co. Ltd. in England, while the actual manufacture will be carried out in the Group's John Inglis plant at Toronto.

The 138,000 kW alternators are being supplied by Metropolitan-Vickers Electrical Export Co. Ltd. and will be manufactured at the Trafford Park works of the Metropolitan-Vickers Electrical Co. Ltd. It is understood that the first two sets will be in commission by the end of 1956.

Conon Valley Scheme. We regret that in giving the list of consulting engineers, contractors, and manufacturers who were concerned with this Scottish scheme (page 114, March 1954) we omitted to state that the consultants for the electrical and mechanical work were Messrs. Merz & McLellan who have been engaged by the North of Scotland Hydro-Electric Board in a similar capacity on many other of the Board's schemes.

Bolted Support for Tunnels

Professor Dr. Techn. L. v. RABCEWICZ, Stockholm,
describes the technique of roof bolting and recounts its advantages, particularly when driving through unstable rock.

PART ONE

SINCE the last world war American tunnelling methods have come increasingly into use in Europe and other parts of the world. As is well known, these methods aim at excavating the whole tunnel section in a single operation in order to obtain space for the complete mechanisation of the different operations. Where unstable rock is encountered, full-face advance is made possible by supporting the roof and walls of the tunnel with steel arches, which are later embedded in the concrete lining. It is surprising how these methods have been introduced in such a short time in a profession so conservative as tunnelling. The reasons for this are the constant rise in wages as well as the endeavour to reduce the time of construction; and an important factor that has largely, although indirectly, contributed to the development of these methods abroad has been the financial aid granted by the United States to war-ravaged countries. American engineers controlled nearly all the big construction projects of this kind in the countries concerned, and were largely responsible for their design, especially in such countries where there was a lack of engineering staff. A large number of big hydro-electric projects are now being built outside the United States under American management, and this has consequently led to the introduction of American tunnelling methods and to the specification of their use by contractors.

The way in which methods and equipment for tunnelling have developed in the last years is revolutionary, due not only to the reasons already given but also to systematic and costly research work carried out not only in the United States but also in Europe, mainly in Sweden.

Although the purpose of this article is not to deal with this development but to consider a modern method of tunnel support in unstable rock, it will not be out of place to offer a brief criticism of the steel-arch method of support.

If we compare the economies of steel-arch supports with the older European tunnelling methods we reach some interesting conclusions. The cost of driving a tunnel through unstable rock is governed principally by the outlay on wages, explosives, steel, wood and cement. A short calculation shows that the steel-arch method is certainly economic in the United States where relatively high wages and low costs of material promote such a method, but in countries where the relation between wages and material costs is reversed this method does not prove to be economic. For such cases the modernised European tunnelling methods, which divide the cross section into a sequence of faces, are more advantageous, and they are also faster, especially in long tunnels in really bad rock. But if the rock does not need any temporary support, full-face driving is no doubt the most economical and far superior to the old European methods, even in countries with low wages and high material costs.

Recently, however, tunnel engineers have started

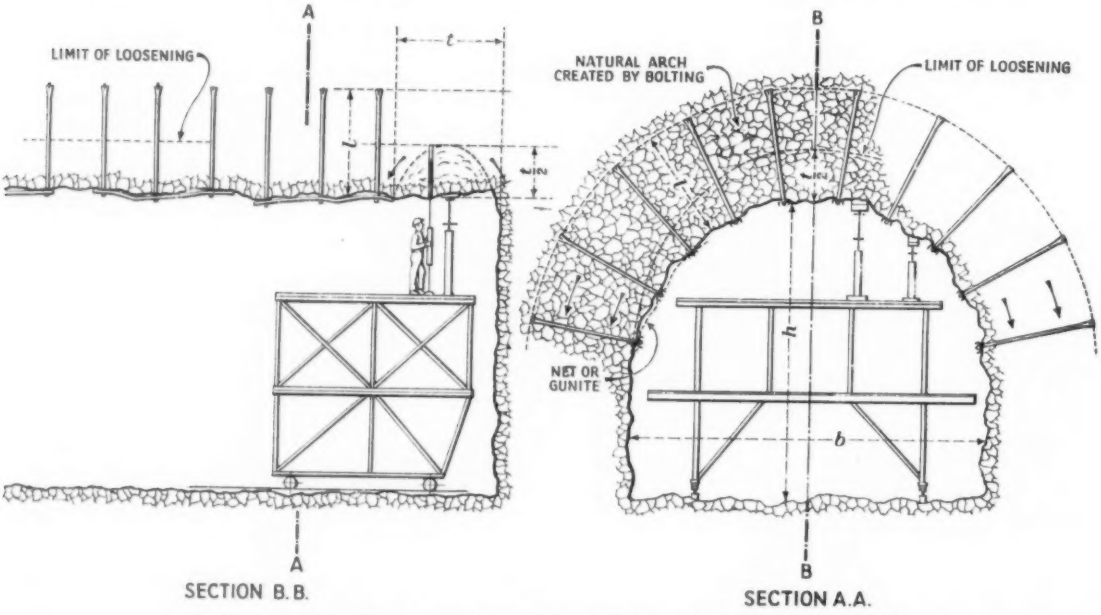


Fig. 1. Diagrammatic sections demonstrating principles of roof bolting

to introduce a method of support for tunnelling in unstable rock known as "roof bolting"—a method which has been used for many years in mines in the United States. The use of roof bolting there is rapidly increasing. Since the first systematic tests were commenced in one mine in 1947, no less than 50 mines employed bolting by the beginning of 1949; by the end of the same year the number had risen to 150, and in 1951 500 mines had taken over the system, 450 out of which were coal mines. During the year 1951, 75 million tons of coal were mined under bolted roofs.[2] Roof bolting follows the simple and ingenious principle of fastening the loose rock near the surface to the solid rock above by means of anchor bolts instead of supporting it from below. This technique not only supports the surface rock but assists it to act as a load-carrying element.

The results obtained to date with roof bolting have been so satisfactory, and its technical advantages are so obvious, that in the writer's opinion the method will before long largely replace the use of steel arch supports as well as the older European tunnelling method, as the latter two methods can be considered to be economical only where geological conditions call for forepoling.

Theoretical Principles of Roof Bolting

Immediately after a tunnel has been driven for the length of one round t (see Fig. 1) the rock in this section expands and settles slightly, developing a double arch effect. In the longitudinal direction of the tunnel the arch rests on the still untouched rock at the front and on the already consolidated portion (see arrows in Fig. 1). The second arch effect, perpendicular to the axis of the tunnel, is given by the form of the roof, which is usually an arch in tunnels.

How long this combined arch will stand without support depends on the geological conditions, the length of the round t and of the radius of the tunnel roof, but in most cases, even in badly disintegrated rock, it will be possible to maintain this natural arch for a practicable span t for at least a couple of hours. If necessary, specially dangerous places can be temporarily supported from the drill jumbo. This means that the rock must stand until the blast fumes are removed and the mucking is accomplished. The limits of the method, as regarded from the stability of the surrounding rock, are consequently very close to a geological condition which requires forepoling.

If the natural arch is not supported immediately after the mucking, it will continue to sink down slowly until it disintegrates. In the meantime the top of this vault is already behaving as a bridge by forming the next arch. The process will continue until the radius is small enough to reach equilibrium.

The portion that is liable to fall is generally parabolic in cross section, having a depth $\frac{t}{2}$, though the loosening process will never go as deep as this if the movement is stopped by quick support. Nevertheless it will be expedient to make the bolts no shorter than t, i.e., twice the depth of the presumed maximum loosening. The natural surrounding rock of the cavity is in this way transformed into a protective arch the thickness of which is given by the length of the bolts, $l \geqq t$, where $l \geqq \frac{b}{3}$ to $\frac{b}{4}$, as the arch also must have a certain relation to the width of the tunnel. This protective arch will function as long as it remains intact; consequently, also, the rock surface between the bolts must not be allowed to loosen, and this can easily be prevented by means of wire netting or by a layer of gunite.

The arch-shaped cross section of a tunnel is of course much more favourable for roof bolting than the flat roof which usually results from the mining of bedded deposits, in which case the bolts have to withstand shear stresses like stirrups in a reinforced-concrete beam, and it would be expedient to ensure that the bolts of a beam fitted tightly in the holes, leaving no gap. Unfortunately, this is impossible as the holes are seldom perfectly round and there must, moreover, be some space left to insert the somewhat larger portion with the wedge. Consequently the shear forces have to be absorbed by the friction between the rock layers, a condition that can be obtained to a considerable extent by clamping them together by bolts. In addition to the friction a slight unevenness of the surface of the layers, which can always be relied upon, will very much increase the resistance against movements between the surfaces, having the effect of dowels.

The rock receives a prestress by bolting and the bolts have consequently to follow the static principles of prestressing in reinforced concrete as much as possible. As it is not possible to place the bolts in the way of stress bars at the lower side of a beam, they should at least be given an oblique position in order to take the place of bent-up bars and stirrups (see Fig. 2).

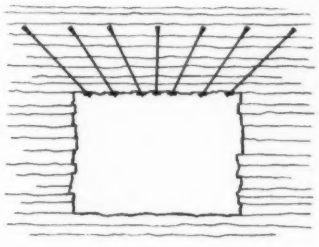


Fig. 2. Roof bolting in a flat roof with horizontal strata

With an arch instead of a beam the shear forces will be greatly reduced by the vault effect, but even in arch-shaped roofs shear forces can be caused by joint systems, especially by systems of parallel layers, e.g., sedimentary formations, schists, etc. Hence it is of greatest importance for every bolt not only to exert a strong prestress to the rock but also to set it in a direction which answers to the static demands of the geological conditions, as shown in the schematic sketches in Fig. 3 for three different joint systems.

Just as a static member of reinforced concrete must be prestressed before receiving the load, the rock also has to be prestressed by bolting before the load develops. This means that the space t in Fig. 1 must be bolted immediately after blasting and at the same time as the next round is being drilled.

The space between the bolts is chosen in accordance with the length and diameter of the bolts. Assuming, for instance, that a 1 in. bolt is given a load of 12 tons, taking into consideration a sufficient factor of safety, this would correspond to a rock volume of

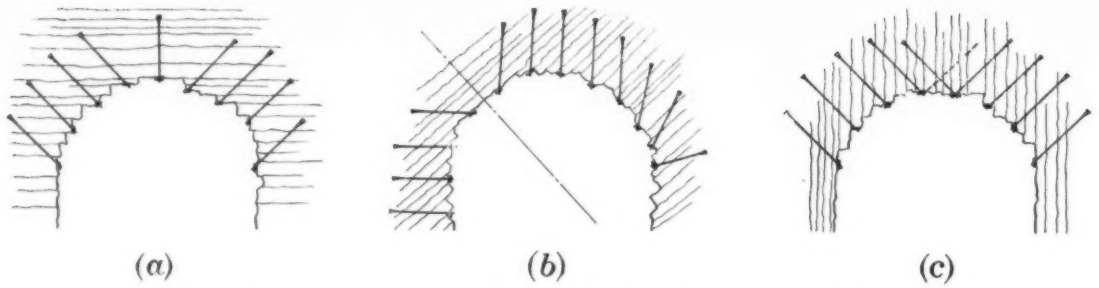


Fig. 3. Roof bolting in strata running at various angles of dip

4·5 cu. m. at a density of 2·65 tons per cu. m. If the length of the bolt allows a thickness of the protective arch of 2·5 m., each bolt will consequently carry an area of the roof of $\frac{12}{2{\cdot}65 \times 2{\cdot}5} = 1{\cdot}8$ m².

For special geological conditions—for instance, for the examples shown in Fig. 3—any increase in the number of bolts will necessarily depend on the thickness of the layers and the nature of the rock.

Steel bolts can be divided, according to the method of anchoring, into the common slit-and-wedge bolts and the so-called "expansion bolts." The first type is anchored by driving the bolt against the bottom of the drilled hole to expand a wedge in the slotted tip of the bolt, whereas the expansion bolt has a device which widens the anchoring portion increasingly with the tension exerted by tightening the nut. With expansion bolts either a cone is used to widen a sleeve or two wedges (see Fig. 4).

The limit of the geological quality of the rock in the bolted area in case of an arch virtually depends on the possibility of obtaining a solid anchoring. As there is no space for any deformation, theoretically even a vault of sand would stand and carry a considerable load if bolts could be anchored in it and loss of material towards the open space could be impeded. Anchoring is certainly the principal practical problem connected with this method. The rock, as well as the anchoring part of the bolt, are exposed to shear, and the larger the contact surface between rock and anchor and the greater the friction, the better is the anchoring effect.

Nevertheless, experience has shown that in a chemically sound and hard rock anchoring is not the weakest point of the construction, as it is known from numerous tensile tests that a 1 in. bolt, for instance, usually breaks at the thread with forces between 20 and 24 tons before the anchoring gives way. But this is not the case in rock of inferior quality, as the following results of research work will show. In order to establish a scientific foundation for the considerable utilisation of roof bolting in the Ruhrgebiet, which has to deal with quite poor rock conditions, some very interesting tests have recently been made there[11].

The tensile tests executed with roof bolts in sandstone and schist showed that the bolt slowly glides

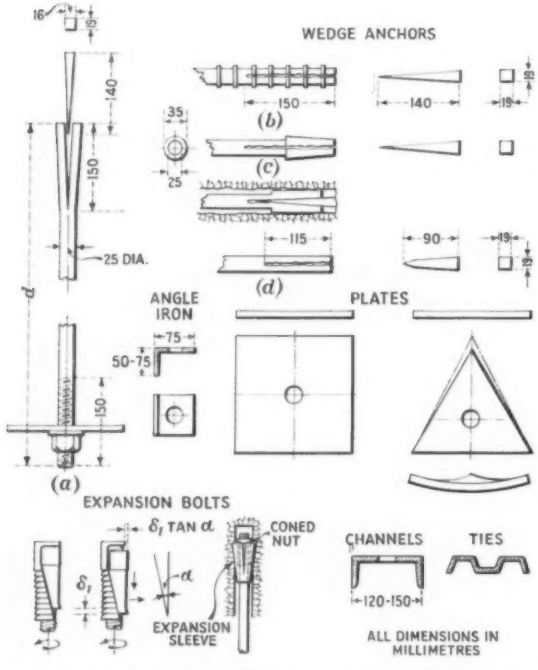


Fig. 4. Details of wedge anchors, expansion bolts and ancillary roof-bolting fittings

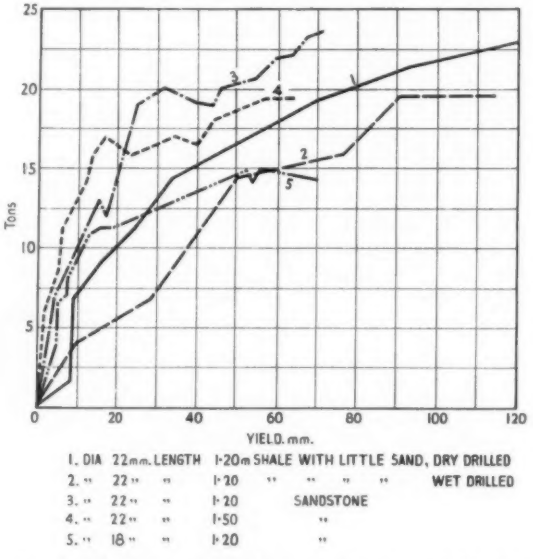

Tons
YIELD. mm.
1. DIA 22 mm. LENGTH 1·20 m SHALE WITH LITTLE SAND, DRY DRILLED
2. " 22 " " 1·20 " " " " " WET DRILLED
3. " 22 " " 1·20 SANDSTONE
4. " 22 " " 1·50 "
5. " 18 " " 1·20 "

Fig. 5. Yield of roof bolts as a function of load in various rocks

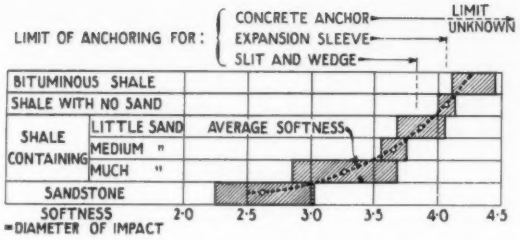


Fig. 6. Classification of the suitability of rocks for roof bolting by means of the impact tester

out under the applied stress. The same phenomenon had been observed by the author in his tests with anchoring in decomposed gneiss. The distance through which the lower end of the bolt moves as a function of the applied load—i.e. the yield—is shown in Fig. 5.

The yield of a bolt measured during these tests includes, of course, not only the distance which its anchor moves but also the temporary and the permanent elongation of the bolt. Further, in using expansion bolts the bolt will pull out a short distance, pressing the expanding mechanism more firmly against the rock, if the bolt has not been sufficiently prestressed while setting it. If this is the case, the diagram shows a flat rise at the beginning, becoming abruptly steep as soon as the expansion has finished. (See test 2 in Fig. 5.) The curves of tests 1 and 2, made in a schist containing only little sand, are flatter than the curves 3, 4 and 5 which have been made in sandstone. Wet drilling of the hole in relatively soft rock instead of dry drilling makes the anchor yield easier, which can be seen from test 2, which is considerably flatter than curve 1. With test 5, made with a thinner bolt, the steel starts to flow at 11 tons and 15 mm. yield.

In order to classify the rock with respect to its ability to accept anchoring, its hardness has been determined by a special apparatus. A small steel ball is shot by a spring with constant force against the rock, and the impact leaves a small cavity, the diameter of which can be measured. Repeated tests with the same kind of rock varied only within the limits shown in the graph reproduced in Fig. 6. The diameter, measured in mm., gives an inverse indication of the hardness of the rock. A remarkably accurate classification of the rock with respect to its capacity for anchoring can be obtained in this way, which should be completed by exact petrological descriptions. According to the tensile tests the limits of anchoring for expansion bolts was found to be "softness 4." This corresponds petrologically to a shale without sand. For common slit-and-wedge bolts the limit is somewhat lower.

The yield is, of course, a very important matter in the technique of anchoring. Yield means space for loosening and loosening means increase of load.

Many conclusions may be drawn from these graphs. A bolt of a certain diameter and steel quality should only be given such stress when tightening the nut that there is still a reasonable safety margin before yielding starts. On the other hand, this initial stress, which can be measured with sufficient exactness, should be big enough to exclude yielding caused by the expansion device.

It seems possible to develop this method to the extent of determining what may be termed "bolting data"—this being based on numerous tests and exact petrological descriptions—for any given rock, i.e. the necessary primary stress to be given and the limit of load, the latter being represented by the characteristic point at which the yield curve starts to bend over. In this way characteristic bolting curves can be drawn for the different kinds of rock, a conception of which is given in Fig. 7. In a sound hard rock the critical "yield point" as it may be called (y in Fig. 7) is given by the tensile strength of the steel, while the

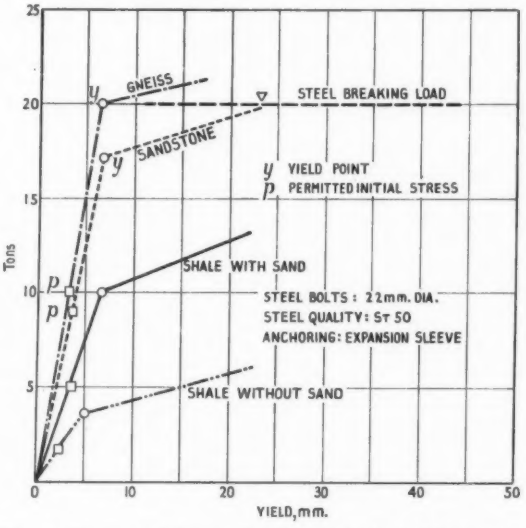


Fig. 7. Suggested form of characteristic bolting curve

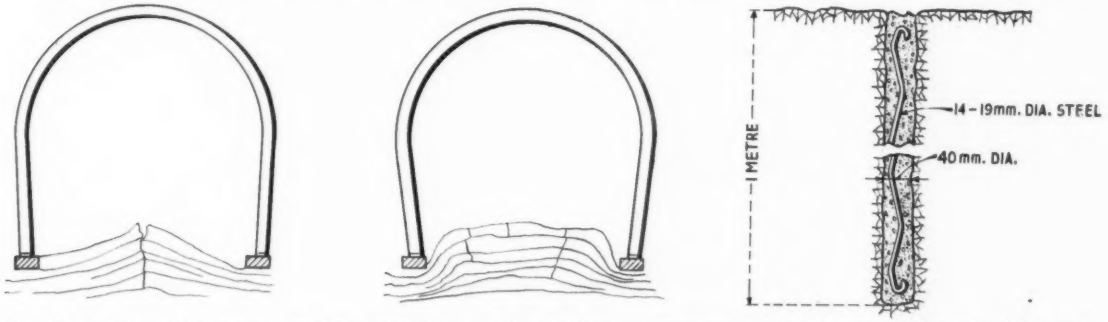


Fig. 8. Reinforced-concrete anchor according to Langecker, to prevent floor lift, examples of which are shown in the left-hand and centre diagrams

initial stress p is appropriately lower. The necessary number of bolts will have to be based on p. The greatest economy is obtained in this case as the steel is fully utilised. The softer the rock the further y moves down, the steel becomes stressed only to a fraction of its tensile strength, and anchoring becomes the centre of the problem. In this case economy points to bolts with a smaller diameter and with a high anchoring effect or to changing the material altogether and using reinforced concrete instead of steel, which offers all the features required if anchoring becomes difficult.

Reinforced-concrete anchors have been tried with excellent results in the coal mines of Hausham (Bavaria)[12] as well as in the Ruhrgebiet[11] in order to prevent floor lift in roadways. In Hausham there was a bituminous marl which gave rise to floor lift and in the Ruhrgebiet there was a seat earth with traces of shales.

The tests made by Dr. Langecker in Hausham were first made with normal cement but this did not give satisfactory results as 60 to 70 hours hardening time was needed to cement the steel sufficiently fast in the holes. This was considered too long with respect to the speed of the squeeze, which started only a few metres behind the face. Straight bars proved to be inferior to bent ones. The best results were obtained by anchors as shown in Fig. 8 using quick-setting cement. Tensile tests made with this kind of anchor showed that the steel of the quality 37—11 breaks at the upper end under loads of 6 to 8 tons for 14 mm. diameter, and 10 to 14 tons for 19 mm. diameter after 24 hours.

In the floor of the roadways in question only single anchors, 1 m. long, were placed on the centreline at distances of 1·50 m. Practically no upward movement could be detected in the anchored portions.

Encouraged by these favourable experiences the engineers of the Ruhr took over the method and concrete-anchored a 180 m. long gallery, the bottom of which was 2·4 m. wide. In this case rows of four anchors, each 1·50 m. long, were placed 0·9 m. apart. In all, 800 anchors were set for 180 m. length. The result of this method was surprisingly good, as in the anchored portion upward movements of up to 10 cm. only were measured, whereas the unanchored portion was squeezed up by 1·40 m. The concrete mixture used in this case consisted of 2 parts Portland cement, 1 part silicate potassium and 8 parts sand and fine aggregate (by volume). Setting was observed after two hours and sufficient hardening took place after 24 hours. It was found important to follow the advance as closely as possible with anchoring and to concrete the dry-drilled holes immediately in order to prevent closing by squeezing.

While prestressing is of fundamental importance for all-metal anchor bolts in order to avoid loosening of the rock, this is not possible or necessary for reinforced-concrete anchors. The latter need neither a plate nor a thread, the rock being held together by adhesion and friction between concrete and rock. No loosening can happen after the concrete has hardened unless the anchor is destroyed.

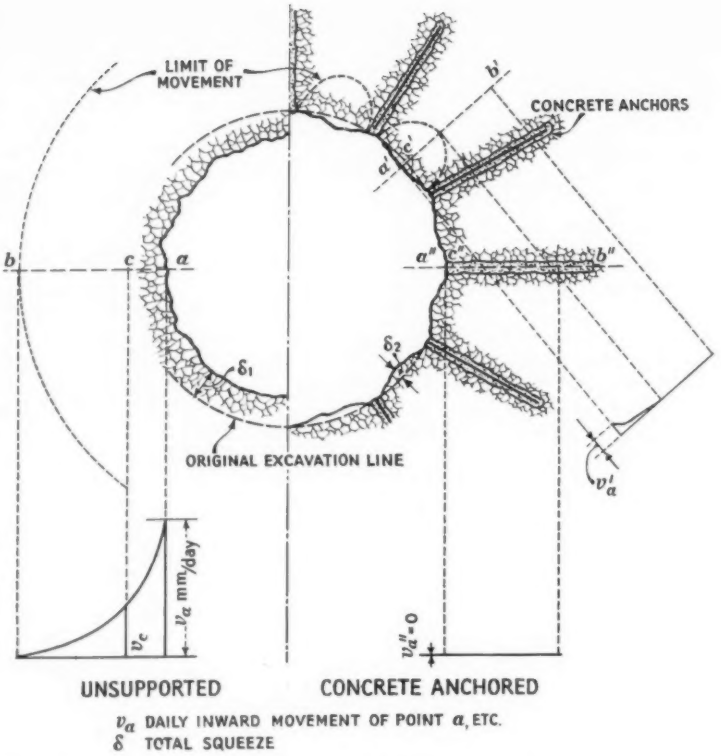


Fig. 9. Diagrams showing effect of concrete anchors in combating rock squeeze

The results obtained with reinforced-concrete anchors invite the conclusion that concrete anchoring is the best and most economic method of support for squeezing rock. Up to now tunnelling through this kind of rock has involved technical difficulties as well as high cost. In such cases it is usually possible to excavate a round without any support, the squeezing starting after a couple of hours in bad cases, and in better ones after some days. The enormous forces developed when the rock expands into the open space are usually counteracted by strong steel arches or rings spaced at short distances with a tight lagging behind. In spite of these expensive measures the results are often negative because the idea of this method of support for squeezing rock is fundamentally wrong. The surprisingly good results of concrete anchoring, up to now unequalled by any other method, indicate it, on the contrary, to be the right system. The effect of the anchors can be explained by the formation of multiple arches between the anchors, the latter being held in place by those portions of rock at a greater distance from the cavity, which are not, or only slightly, affected by the movement (see Fig. 9). The necessary length of the anchors and their centre distances will have to be determined

empirically for each case in the light of circumstances.

To complete the anchor form of support in squeezing rock a net should be attached to the protruding ends of the bars. This is necessary for the safety of the crew as well as to prevent the loosening movement from progressing towards the interior of the rock.

The tensile stress of a steel bolt can always be controlled by a so-called "torque meter"—an instrument which provides a reading of the torsional moment. In this way the initial stress can be ascertained as well as changes in load caused by the anchor yielding or the rock loosening, but the method supposes that the thread is not rusted or clogged. A rusted thread can show the same torsional moment as an oiled thread stressed only to one-third of the latter[11]. Thus suitable results can only be obtained by a torque meter if the threads are clean and oiled.

In order to be independent of this condition a kind of spring washer is now being tried in the Ruhr. With this washer inserted between the plate and the bolt the tension of the bolt can be easily found from the compression of the washer, which corresponds to the force exerted, the system acting virtually as a spring balance. In order to give a bolt the desired primary tension a distance ring can be inserted, tightening of the nut being stopped as soon as the distance ring touches the plate (Fig. 10).

Control measurements of bolted areas have been carried out several times in certain mines in the United States, and have shown astonishingly small variations

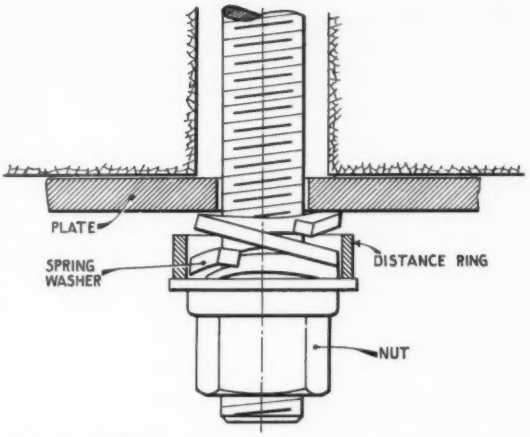


Fig. 10. Spring and washer assembly for measuring the load on a roof bolt

—only plus or minus 10 per cent.—with respect to the initially installed values[2]. In really bad rock higher variations must be expected.

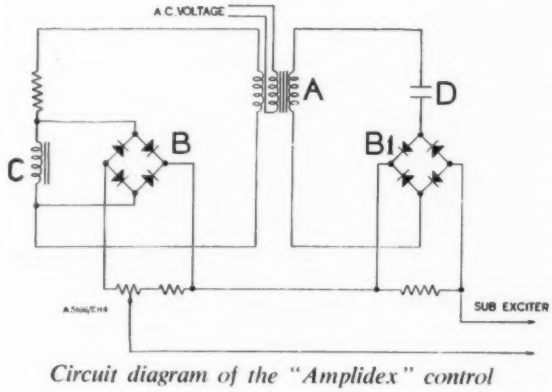
Although it is relatively easy to determine the forces in a steel bolt it is impossible to measure forces with a concrete anchor, as in this case the forces act not at a point, but along the whole surface of the anchor.

(To be continued)

Brush Self-Regulating Alternators

Much attention is now being given to the problem of the close voltage regulation of smaller alternators, as there are many cases where these machines have to operate unattended and where the expense of a normal automatic voltage regulator is not warranted. A typical case that comes within the hydro-electric engineer's purview is the diesel-driven construction station.

The Brush Electrical Engineering Co. Ltd. have developed a series of self-regulating alternators fitted with "Amplidex" system of control. The alternator is of normal design but excitation is obtained from an amplifying dynamic excitation unit which consists of a main exciter to supply the alternator field current and a small sub-exciter, the two being mounted in tandem in a single frame.



Circuit diagram of the "Amplidex" control

To control the alternator from the small power output of the detector circuit a high value of amplification is required and at the same time a rapid rate of response. For this purpose the two exciters are connected in cascade. The field system of the main exciter is laminated and compensated, the field laminations being similar to induction motor stator laminations but with certain teeth removed to form commutating zones. The stator is wound with concentrated excitation windings and a fully distributed compensating winding. The sub-exciter is a simple separately excited machine and has also a laminated field construction.

The alternator voltage is fed through an isolating transformer *A* to two bridge rectifiers *B*, B_1, one shunted by a saturated reactor *C* and the other with a series capacitor *D*. The outputs from the rectifiers are applied to two resistances in series and the difference in voltage across these two resistances supplies the error signal to the sub-exciter. A small rheostat is provided for setting the alternator voltage.

The saturated reactor holds the voltage constant across one rectifier but the voltage of the other varies in direct proportion to the alternator voltage. When the two voltages are equal no current will be supplied to the exciter field. If the alternator voltage varies the exciter field current will vary in magnitude dependent upon the strength and direction of error signal, thereby rapidly correcting the terminal voltage to its set value.

The reference voltage provided by the saturated reactor is sensitive to frequency but so also is the current in the capacitor fed by the rectifier. These two effects are thereby cancelled out and thus no variation due to frequency changes results.

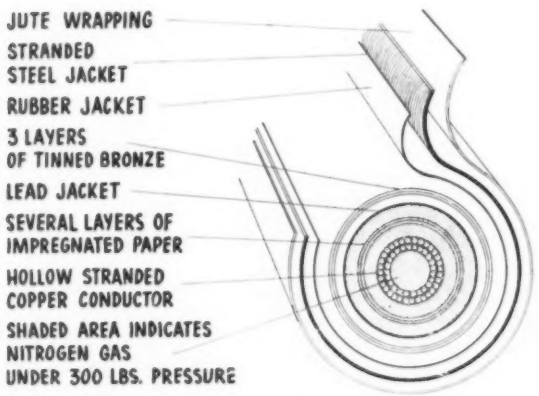
Over the normal range of engine governing, the balance point will remain unchanged, in fact, the fre-

quency can be adjusted from 50 to 60 cycles with only a small change in voltage.

Brush self-regulating alternators with Amplidex control give a voltage regulation of $\pm 2\frac{1}{2}$ per cent. from cold to hot—at variable power factors—no load to full load—allowing for the usual 4 per cent. engine speed variation. When full load at 0·8 power factor is thrown off, the voltage rise is arrested in less than 0·2 of a second and the voltage overshoot is within 20 per cent. of normal voltage. Within the limit of full rated kVA, voltage recovery is obtained in one second or less for any condition of load change.

Notable Submarine Power Cables

As announced in this journal last month the contract to construct submarine power cables for B.C. Electric has been awarded to British Insulated Callenders Cables Limited. It is understood that the successful bid was just over $3,000,000 to manufacture, deliver by ship, install, and finally test the four cables in the circuit. This power link will cross the Gulf of Georgia between the Canadian mainland and Vancouver Island, a distance of about 19 miles.


JUTE WRAPPING
STRANDED STEEL JACKET
RUBBER JACKET
3 LAYERS OF TINNED BRONZE
LEAD JACKET
SEVERAL LAYERS OF IMPREGNATED PAPER
HOLLOW STRANDED COPPER CONDUCTOR
SHADED AREA INDICATES NITROGEN GAS UNDER 300 LBS. PRESSURE

Construction of the B.I.C.C. submarine cable

Mr. Tom Ingledow, the vice-president of B.C. Electric, announced recently that this $5,000,000 project would end for the foreseeable future any danger of a power shortage in Vancouver Island.

The underwater circuit will consist of four separate cables, three for normal operation and the fourth as a spare. In addition, overhead lines will be installed at each end to connect the circuit with the mainland and island systems. The services of the S.S. "Seafisher" have been reserved for transport purposes and she will have her holds especially adapted to accommodate the long coils of cable, which will weigh about 4,000 tons. She is scheduled to sail direct from the Manchester Ship Canal to Vancouver early in 1956. The cables will actually be laid, however, by Her Majesty's Telegraph Ship "Alert," which is one of the few cable-laying vessels afloat able to handle a job of this size.

The cables measure between 4 and 5 in. in diameter and the energy will be carried in a hollow stranded copper conductor not much more than one-third of a square inch in cross section. Around this copper core there will be several thicknesses of impregnated paper, followed by a lead sheathing. Inwards from the lead jacket, towards the centre, nitrogen gas under pressure of 300 lb. per sq. in. will form a permanent insulation. Three thin layers of tinned bronze will separate the lead jacket from a rubber covering which will lie just inside the galvanised stranded steel armouring which will protect the entire cable from rubbing and wear against underwater rocks or other obstructions. An overall wrapping of waterproofed jute will be provided.

The cables are designed for 132,000 V, the highest voltage yet attempted for an underwater circuit, and the quantity of energy that can be transmitted, 120,000 kW, also constitutes a world record. The accompanying diagram, for which we are indebted to B.C. Electric, shows the constructional details.

Rolls-Royce-Powered C.P. Portable Compressor

The Consolidated Pneumatic Tool Co. Ltd. announce the addition of a new model to their range of portable air compressors. This is the standard PO-40-315 plant, fitted with the latest type Rolls-Royce oil engine, and is the first portable air compressor in the world to have a Rolls-Royce power unit. The actual capacity of this plant is 315 cu. ft. per min., at a maximum working pressure of 125 lb. per sq. in. The power unit is the Rolls-Royce type C6NFL six-cylinder oil engine of 93 b.h.p. at 1,250 r.p.m. (12 hour rating) fitted with C.A.V. fuel pump and C.A.V. multi-hole atomisers. It has dry-sump lubrication and 24 V electric starting. A feature of the complete plant is the grouping of all gauges and

Rolls-Royce-powered C.P. portable compressor

switches on one conveniently placed control panel.

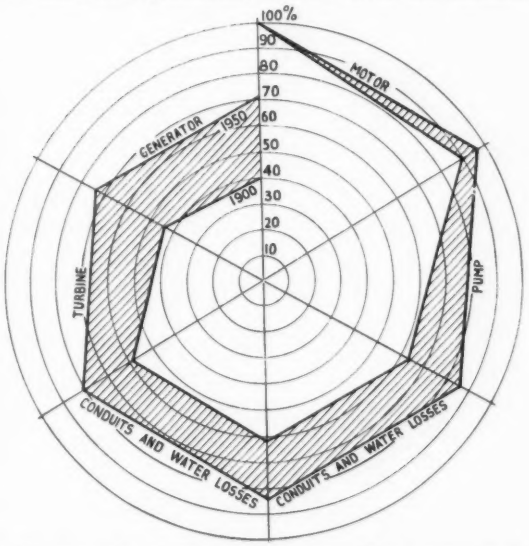
The first of these Rolls-Royce powered compressors has been taken up by a leading civil-engineering organisation and has given much satisfaction, in the course of some months of field service. Now that more engines are available, regular production of the new plant is well under way. From the point of view of servicing and spares, this development will be of interest to users of civil-engineering plant, in view of the increasing use of Rolls-Royce oil engines in other types of equipment.

Abstracts from the World Technical Press

Pumped Storage in Switzerland

A brief account is given, on general lines, of the development of pumped storage in Switzerland. The idea of secondary storage plants met, at first, with a rather hostile reception. This was at a time when thermal energy was available at low prices, and the low efficiency of the motor-pump-conduit-turbine-generator cycle, added to high capital expenditure, was anything but encouraging. The first pumped storage was set up as early as 1882/83 at the Letten plant of the Zurich Corporation, with a capacity of 18,000 cu. m. and a head of 157 m. Seventeen years later, the Choindez and Klus installations followed with heads of 600 and 314 m. respectively. All three plants used reciprocating pumps ,although as early as 1894 a Sulzer vertical-shaft multistage centrifugal pump, the first of its kind, had been installed at the textile works of Creva-Luino, Italy. It was not, however, until 1904 that pumped storage was introduced by a hydro-electric concern catering for public requirements, when the Olten-Aarburg Electricity Works installed a Sulzer four-stage horizontal pump lifting 133 lit. per sec. at 325 m. and absorbing 800 h.p.; this pump alone had an efficiency of 72 per cent., but overall efficiency hardly reached 50 per cent. Slight increases in efficiency were obtained in later installations, such as the Schaffhausen Corporation plant (pumps 78 per cent., overall 52 per cent.), erected between 1907 and 1909, and the Rempen power station, 1925/26 (pumps 80 per cent., overall 55 per cent.). The subsequent slump and exceptionally low coal prices brought development to a standstill, and it was not until World War II that progress was resumed, thanks to the advance of engineering technique which considerably improved efficiency, and to the high price of thermal energy. Overall efficiency then rose to between 65 and 70 per cent. at the Illsee, Etzel and Grimsel plants, and it is now expected that at Peccia, one of the Maggia plants, the overall efficiency will reach about 70 per cent. The cross-hatched area of the appended diagram shows the progress achieved between 1900 and 1950, excluding transformer and line losses. At the beginning of the century overall efficiency was but 40 per cent., and 1 kWh of peak energy required 2·5 kWh of pumped energy, but the latter figure had almost been halved by 1950, decreasing to 1·4 kWh; during the same period, power-input capacity of pumps rose from a few hundred to 60,000 h.p. per unit, while heads have now passed the 1,000 m. mark.

Hydro-electric power economy is favourably influenced by two fundamental factors: increasing coal prices and decreasing rate of interest on capital. Present conditions are therefore clearly to the advantage of hydro-electric over thermal energy. Manufacturers will undoubtedly endeavour to increase overall efficiency by improving the individual efficiency of every part of the equipment; on the other hand, the cost of machinery will have to be reduced by the adoption of higher speeds, resulting in machines of lighter weight. A possible solution appears in the reversible machine, i.e. the turbine capable of assuming pump duties or vice versa. Some of these machines are already in service, but the fact cannot be ignored that this possibility is as yet available only for single-stage pumps, which limit the maximum head to about 400 m. Another consideration is that such a turbine-pump or pump-turbine can only be a compromise between driving and pumping efficiency, and the importance of overall efficiency in secondary-storage plants is such that no means of improving it can be neglected. There is therefore little probability that the reversible machine



will prove the solution in all cases. The present advance of engineering technique, however, paves the way for well adapted and economically advantageous installations. (R. Thomann, *Bulletin Technique de la Suisse Romande*, Vol. 79, No. 11/12, 13.6.1953, p. 214, 4 pp., 7 ff.)

High-Strength Concrete

An account is given of the general discussion of Group No. 6 at the 1953 Engineering Conference in Melbourne, on "Areas of the Commonwealth in which High-Strength Concrete may be Produced from Local Aggregate." From this interesting discussion, we should like to single out some of the details of the report on the tests carried out by the Co-ordinator-General's Department of Queensland from 1951 to 1953. The 1951 series dealt with the comparison between gravel and crushed granite aggregates, with a cement content of about 8 cu. ft. to the cubic yard of

concrete and a water content of about 3·5 gallons per cu. ft. of cement. Maximum size of aggregate was 1·25 in., and both water-bath and oil-curing were applied, standard test cylinders being used. The results indicated that:—

(a) Gravel concrete was the more workable.

(b) Average strengths at 28 days were 4,586 lb. per sq. in. for the crushed granite concrete.

(c) "Scatter" of results was 26 per cent. with gravel and 16 per cent. with crushed granite.

(d) Oil-curing showed up poorly in the one-year results.

During the 1953 tests, which were done under field conditions, the following steps were recommended to obtain high-class concrete suitable for pre-stressed work:—

(a) Careful storage of all materials.

(b) Adequate pre-use testing of cement.

(c) Work to be protected from weather, particularly in hot climates.

(d) Extremely heavy vibrations. (*The Journal of the Institution of Engineers, Australia*, Vol. 25, No. 9, September, 1953, p. 196, 1 p.)

Flow in Open Channels

This paper, No. 1128, originated in the Perth Division of the Institution of Engineers, Australia. Turbulent flow only is dealt with, since laminar flow in open channels can be reproduced only under strict laboratory conditions with small channels. The paper is divided into the following sections:—Uniform Flow, Steady Non-uniform Flow, Interpretation of Non-uniform Flow Equation, General Features of Flow, Zones of Flow, Location of Hydraulic Jump, and Application of the Non-uniform Flow Equation. (K. Sylvester, Associate member I.E.A., *The Journal of the Institution of Engineers, Australia*, Vol. 25, No. 9, September, 1953, p. 155, 8 pp., 25 ff.)

Electrical Energy in Austria

The development of electrical energy in Austria in 1951-52 is reviewed from both the aspect of home consumption and of exchanges with foreign countries, and the possibilities of further development are examined. Aggregate production increased from 7,375 million kWh in 1951 to 8,000 million kWh in 1952, imports (45 and 85 million kWh, respectively) and exports (849 and 1,025 million kWh, respectively) being taken into account. A separate table gives the figures for commercial electricity producers alone, divided into provinces as well as into types of plants, and shows the ascendancy gained by hydraulic over thermal output. The overall figures for the whole country are 5,222·2 million kWh (run-of-river plants 3,423·4, storage plants 1,798·8 million kWh) for hydro-electric, against 1,037·6 million kWh for thermal production.

The first part of the new development plan comprises new plants and reconstructions scheduled for completion in 1957, with an aggregate capacity of 489,600 kW and an average annual output of 1,314 million kWh. Among the major projects in progress are:—Reisseck (97,500 kW), Rosenau on the Enns (25,200 kW), Braunau (45,000 kW), and Jochenstein (70,000 kW); these two latter, in Upper Austria, are being erected in conjunction with an electrical undertaking in neighbouring Bavaria.

The second part of the plan embraces the regulation of existing diversions, and the enlargement of reservoirs with a view to increasing the present yearly production by 402 million kWh, most of it (360 million kWh) by connecting the Möll River with the reservoirs of the first and second steps of the Kaprun scheme.The third part, now practically completed, covers thermal plants. (*Quaderni di Studi e Notizie*, Vol. 9, No. 143, p. 194, 3 pp., 4 tables.)

Harsprånget 380 kV Transmission

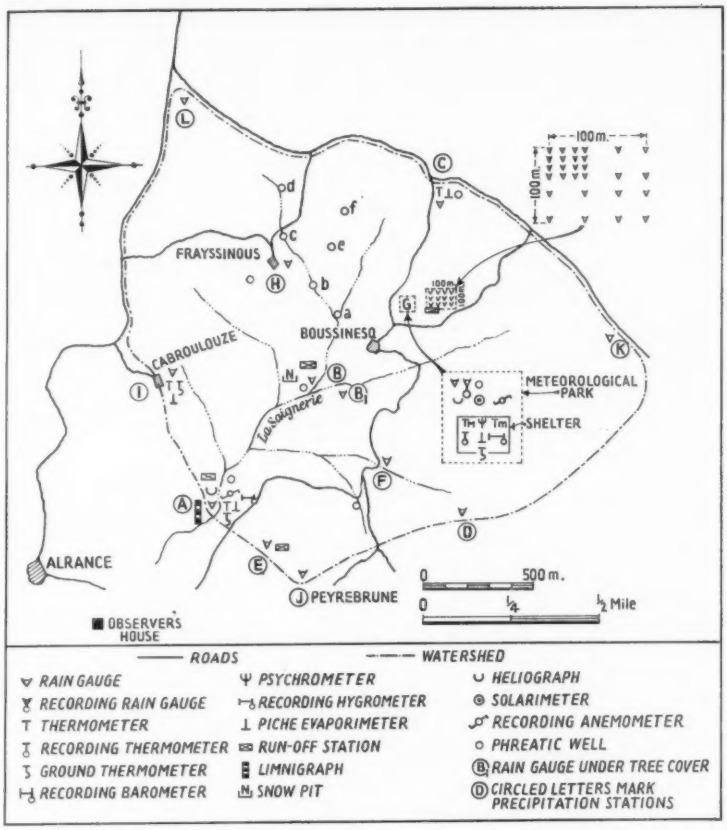
Following discussion of the Harsprånget transformers in the May-June 1953 issue (see WATER POWER, November 1953, page 440) the July-August and September-October issues of *ASEA Journal* are devoted entirely to various other aspects of this pioneer transmission system. The July-August issue contains articles on the high-voltage circuit breakers, isolators, current transformers, and lightning arresters, and the September-October issue articles on the 380 kV switchyards, control equipment, fault location, and service problems. ("High-Voltage Circuit Breakers for the Harsprånget Power Transmission," by I. Lindström, "380 kV Isolators," by T. Hallonborg, "Current Transformers for 380 kV," by B. Olsson, "Lightning Arresters Protecting the 380 kV Power System," by B. Grundmark, *ASEA Journal*, July-August 1953; "The 380 kV Switching Stations," by J. Melkerson and S. Svidén, "Some Notes on the Control Equipment for the 380 kV Stations," by B. Larsson, "Fault Protection in the Swedish 380 kV Stations," by V. Sterner, "Some Aspects of the 380 kV System in Service," by F. Petri, *ASEA Journal*, September-October 1953).

Flood Computation

Hydrologists and dam designers rightly lay stress on accuracy in flood computation, seeing that the complete or partial destruction of a structure, not to mention other catastrophic damages, may depend on reliable information of this kind. This led to hydrological division of the Electricité de France research department to set up, two years ago, an experimental catchment area at Alrance, Aveyron, the layout and equipment of which are shown in the appended map.

The author of this paper, proceeding from the hydrograph unit method, explains how he applied it by investigating the trend of the curve resulting from a flood caused by an isolated shower at the Alrance testing ground; he then analyses the degree of accuracy which may be ascribed to the method as a function of the errors inherent in rainfall measurements, their extrapolation in time and space, and the determination of the run-off coefficient. A comparison between computed and actual hydrographs—the latter plotted according to the limnigraphs of the Alrance outlet—shows that improved accuracy is necessary but that, until proof to the contrary is produced, the use of the hydrograph-unit method is fully justified.

The instance of the isolated shower does not, however, apply if no limnigraph is available at the outlet of the area under investigation, and methods which permit the hydrograph to be plotted as a function of topographic characteristics (area, length of streams, gradients) must be resorted to. The author finally analyses one of these methods: "Unit hydro-



graph lag and peak flow related to basin characteristics," as set forth by Taylor and Schwarz in the issue of April 1952 of the *Transactions of the American Geophysical Union*. It is claimed, in conclusion, that once the rainfall is known the problem of the run-off coefficient constitutes the essential basis for flood computation. (P. Cappus, E.D.F. Research Engineer, *Proceedings of the Société Hydrotechnique de France*, published by *La Houille Blanche*, Vol. 8, No. A, March-April 1953, p. 159, 9 pp., 13 ff.)

Huai River Project

An account is given on general lines of the first attempt by Chinese technologists, assisted by a Russian expert, to achieve complete flood control on this great tributary of the Yangtze river. The keypoint for control of the tributary waters from the upper reaches of the Huai river is Chengyangkwan. Here, during the 1950 spate, the discharge rate was estimated at 12,000 cu. m. per sec., exceeding by no less than 5,500 cu. m. per sec. the carrying capacity of the channel downstream of the town .Computations finally established that the setting-up of a large-scale regulating system, based on a storage dam at Jenhochi, would limit the maximum discharge at Chengyangkwan to 6,000 cu. m. per sec. In view of the shortage of timber and the lack of a domestic supply of sheet piling, M. Bukhoff, the Russian consultant, introduced the Huai Harnessing Committee to the new Soviet practice of building hydraulic works without foundation piles. All other difficulties, some of them of a very serious nature, were overcome, and after replacing the foundation soil by a 2 m. layer of coarse sand, the work was completed ahead of schedule. The Jenhochi regulating system required 24,000 cu. m. of reinforced concrete, 73,000 cu. m. of stonework, 749 m. of sluice-gate installations and over 2 million cu. m. of earthwork. A remarkable feature of this enterprise is that it was fully carried out without the help of any contractor. (Chien Chen-Ying, Director of Jenhochi Dam Construction, *Indian Journal of Power and River Valley Development*, Vol. III, No. 2, p. 18, 4 pp., 2 ff.)

Theoretical Flow Research

In current hydraulic practice dealing with open-channel flow, one of the basic hypotheses of calculation is that the curvature of the streams is usually accepted as being very slight. This simplification is generally justifiable, but obviously leads to absurd conclusions when the curvature is not slight. It is, for instance, common knowledge that in the transition from torrential to tranquil flow, the classic calculation leads to an infinite slope of the water level. Taking the curvature into account considerably complicates the computation, and in spite of such a shrewd analyses as that of Boussecq, research has tended to be discouraged.

This thesis, submitted to the Faculty of Sciences of the Paris University, resolutely attacks the problem, works out solutions for both permanent and transient flow, and opens a wide field of investigation to the hydraulic engineer who is willing to familiarise himself with some of the mathematical niceties. (François Serre, *La Houille Blanche*, Vol. 8, No. 3, June-July, 1953, p. 374, 15 pp., 12 ff.)

Hydro-Electric Developments in the Soviet Union

Drawn up as early as 1920, when the country was still in a turmoil, the first Soviet electrification plan had been fulfilled three times over by 1936; and in 1952 the yearly output had reached 117,000 million kWh, a more than 70-fold increase over the latest pre-revolution figure of 1,600 kWh. Endowed with a water-power potential which, in average hydrographical years runs into 3,000 million kWh, and probably surpasses that of any other country in the world, the Soviet Union was bound to give hydro-electric development a prominent place. As early as 1919 work began on the Volkhov hydro-electric station, a great venture for its time; under the GOELRO plan, no less than 31 major hydro-electric plants, including the Dnieper project, were set up in European and Asiatic Russia between 1928 and 1933, and towards the outbreak of World War II Soviet waterpower accounted for 10·7 per cent. of the country's aggregate electric output.

Owing to the importance of agriculture in Soviet economy, multi-purpose development is the rule, and power supply combines with flood control, irrigation, water supply, and navigation. To single out but a few examples, the Mingechaur project, now under construction on the Kura river in Transcaucasia, will provide for electric power, irrigation and flood control in the Kura-Araks lowland; the Gorky station will supply electricity to the neighbouring industries, in addition to improving navigation above and below the city of Gorky, which is one of the largest river ports in the Union; two hydro-electric stations have been built on the Moscow Canal, which connects the Volga and Moscow rivers, a scheme which enables the largest Volga steamers to sail up to Moscow itself; and on the upper Volga, a huge artificial lake has been set up in connection with the Shcherbakovskaya power station.

The programme launched in 1950 comprises, among others, large projects on the Volga, Dnieper and Amu Darya rivers. The two Volga plants at Kuibyshev and Stalingrad are in course of construction; the former, the largest plant in the world with its 2·1 million kW capacity, will provide Moscow, over a 880 km long, 400,000 V transmission line, with 6,100 million kWh a year in addition to the 4,000 million kWh provided by Stalingrad. These two plants are to be commissioned in 1955 and 1956, respectively. The 250,000 kV Kakhovka station on the Dnieper will produce yearly 1,200 million kWh. In Central Asia, the construction of the main Turkmen Canal, stretching from the Amu Darya to Krasnovodsk, is steadily proceeding; beginning with the Tahia-Tash plant, three hydro-electric stations, aggregating 100,000 kW, will be operated by carefully selected falls on this canal, the main purpose of which is to ensure transit communications between Central Asia and European Russia through the Caspian Sea and the Volga. The speeding up of the V.I. Lenin Canal, a project initiated in 1948, is also included in the 1950 programme; in addition to connecting the Don with the Volga at Stalingrad, this canal, open to navigation since July 27, 1952, comprises the Tsimlyanskaya installations with a vast reservoir, a 160,000 kW hydro-electric plant, and irrigation and water-supply facilities for 750,000 and 2,000,000 hectares, respectively.

The fifth Five-Year Plan (1951-55) provides for the further expansion of hydro-electric development; besides the Kuibyshev installations, the Kamsk, Gorky, Mingechaur, Ust-Kamenogorsk (Kazakhstan), other stations, aggregating some 2 million kW, will be put into operation. The building of new stations will start at Cheboksary (Volga), Votkinsk (Kama), Bukhtarminsk (Irtysch) and a number of other places. Provision is also made in the plan for the harnessing of the water resources of the Angara river in the Irkutsk regions.

The author of this survey considers that the following prime factors have enabled the Soviet Union to carry these developments into effect:—

(a) Experience accumulated in the past decades in the setting up of hydro-technical installations under widely differing conditions;

(b) The extensive participation, at both planning and building stages, of scientific research institutions, headed by the Academy of Sciences.

(c) The equipment of the construction plants with efficient labour-saving machines. (Professor Innokenti Kandalov, *Indian Journal of Power and River Valley Development*, Second Annual Number, 1953 (incorporating March issue), p. 42, 9 pp., 8 ff.)

Concrete Research

A new process developed by R. J. Claus and J. T. McCall, assistant professors of engineering at the Michigan State College, is reported to be successful in speeding up the hardening and strengthening period of concrete by as much as 60 per cent. Results showed the acceleration takes place if a newly-developed pellet-shaped form of anhydrous calcium chloride is added to Portland-cement concrete during mixing, instead of the familiar flakes which have been used as a strength accelerator for about 50 years. (*Engineering News-Record*, Vol. 151, No. 19, Nov. 5, 1953, p. 70.)

Australian Conference on Structures

Among the papers read and discussed before the Conference held at Newcastle University College, Australia, in September, 1953, under the auspices of the Newcastle Division of the I.E.Aust. and the N.S.W. University of Technology, we draw attention to the following:—

"The Provision in Peacetime Construction against the Possibility of Future War," G. E. K. Pit.

"Prestressing in Structures of Ductile Material," Prof. A. J. Francis.

"Design of Prestressed Concrete," P. B. Stewardson.

"Prestressed Concrete Construction Methods," J. M. Antill.

"The Prestressed Concrete Tower at Warragamba Dam," C. J. Doney.

"Limit Design Theory for Reinforced Concrete," F. A. Blakey. (*The Journal of the Institution of Engineers, Australia*, Vol. 25, No. 9, September, 1953, p. 198.)

CLASSIFIED ADVERTISEMENTS

Announcements for this column can be accepted up to the 8th of the month for the following month's issue. The charges are fourpence per word with a minimum of 10s. Box No. facilities 2s. 6d. extra. In order to avoid accountancy it would be appreciated if instructions to insert were accompanied with remittance.

IMPERIAL COLLEGE OF SCIENCE & TECHNOLOGY

ENGLISH ELECTRIC COMPANY'S
BURSARIES IN HYDRO-POWER ENGINEERING

NOTICE IS HEREBY GIVEN that a number of English Electric Company Bursars in Hydro-Power Engineering will be elected in June, 1954. The Bursaries are of the value of £250 for one year tenable for postgraduate study in the Civil Engineering Department of the Imperial College. Bursars pay the appropriate College Tuition Fee. The Bursaries will be recommended for supplementation by the Ministry of Education.

Bursars who successfully complete the course will be eligible for the award of the Diploma of the Imperial College (D.I.C.).

Candidates should have an Honours Degree in Engineering or an equivalent qualification, and applications should be received before 1st June, 1954, by the Deputy Registrar, City & Guilds College, Exhibition Road, London, S.W.7, from whom further details may be obtained.